ENGINEERING

SEP 22 1958
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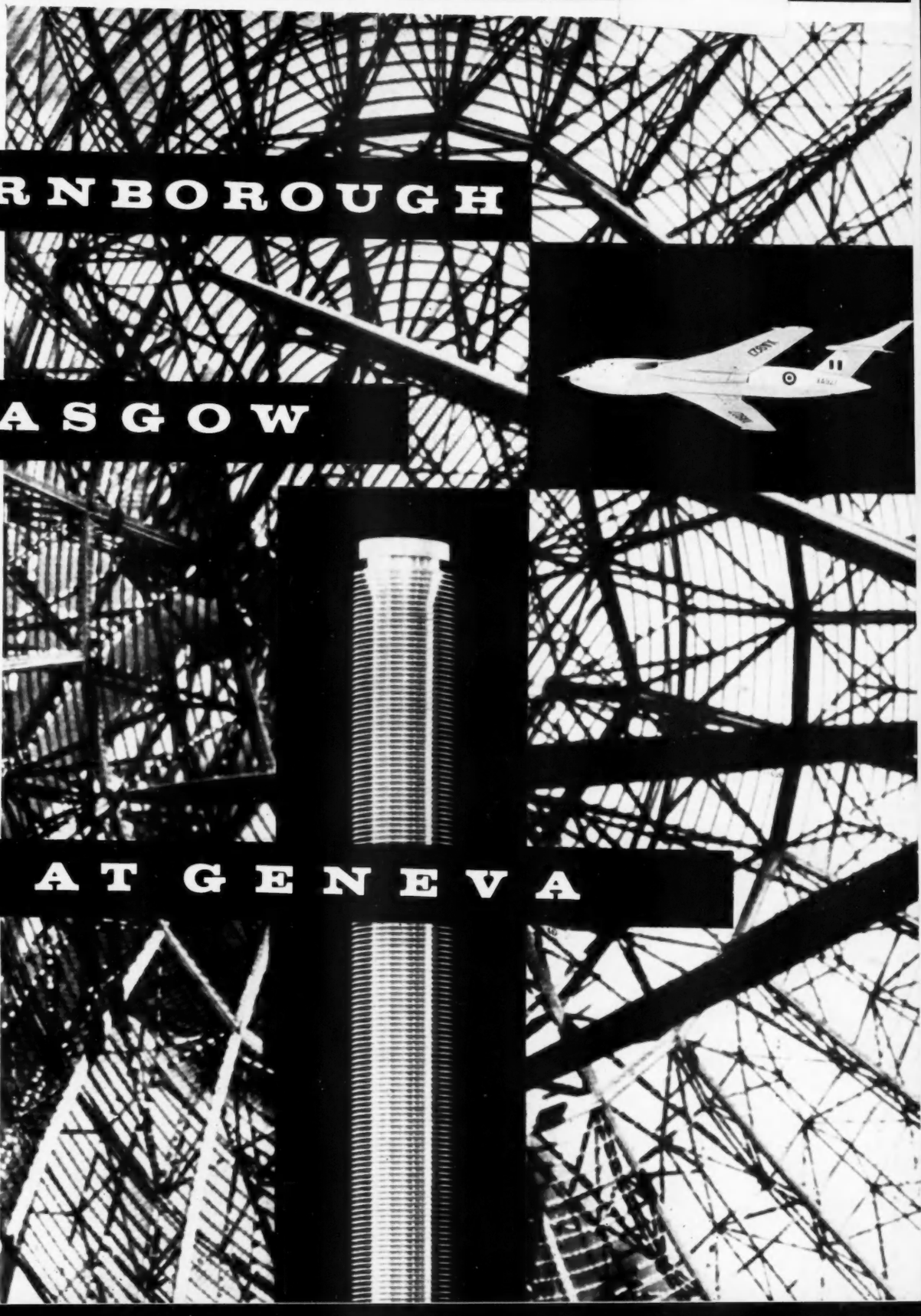

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ENGINEERING
PUBLISHED EVERY FRIDAY
Vol. 186 No. 4826 5 September 1958

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Slack Adjuster

BETWEEN the wars there was a man who had been born into a humble working class family. At school he had usually been near the bottom of the class. His parents expected little of him. When he left school there was mass unemployment in the country and there was no job for him. He had his first break about a year later, but it didn't last long; he was unemployed again. With the rise in employment before the Second World War he was drawn into productive work, but neither then nor since has he been a particularly useful worker. For him, life has been a series of selection tests and at nearly every one he has been unlucky. When he is out of work he lives on the State; when he is in work he contributes less than his fair share.

Since the Second World War few boys leaving school have stepped into the same situation. Most of them have gone straight into employment. To-day a boy cannot be sure. If he lives in Scotland or Wales, 3½ per cent of the employable men are already unemployed; in Northern Ireland, 8 per cent; in London and certain areas of England, less than 1½ per cent. Taking the country as a whole, the figure is less than 2 per cent, but statesmen and economists are unhappy because the total of unemployed, which usually falls in the first half of the year, has remained fairly constant, and at a higher figure than at any time in 1956 and 1957. What is being done to give some assurance to the boy who leaves school to-day? There are four parties who between them share the responsibility; the Government, industry, the trade unions, and the nation's economic consultants—the Cohen Committee. The powers of each are limited. The Government have the widest powers, but they inevitably delegate much of the detail to industry. For political reasons they must try to maintain reasonably full employment, but their consultants have warned them against the dangers of going too far. The Government must therefore maintain a balance which is so delicate as to be almost unstable. Industry starts from a different premise: for the individual firm the first consideration is to stay in business by producing goods at a profit; and the nationalised industries should be no different in this respect. The trade unions' position is even less helpful. Their leaders may be well aware of the dangers of over-full employment, but they cannot subscribe to the view that a little unemployment is healthy, for fear of losing the confidence of their members. That is where the consultants come in: they regard a little unemployment as essential. The Cohen Committee's second report says: "If policy is successfully directed in future towards avoiding the peak levels of demand as we have known them in recent years, it can hardly be expected that the average level of unemployment over a period of years will be quite so low as in the last decade."

The Cohen Committee say that the two main objectives of economic policy are: (1) full utilisation of the national resources of labour and capital, and (2) stable prices. Why can we not have both? If a small proportion of unemployment is necessary to maintain stable prices, does it necessarily follow that the unemployed must remain wholly idle? Surely some way can be devised to employ two or three per cent of the working population without their work and wages contributing to the vicious circle which produces inflation?

It should not be impossible to mitigate the hardships of the unemployed and to do away with the indignities of having no work. Since it is a regional problem, it could be tackled on a regional basis. Attracting industry to an area is a slow and inflexible method of correcting temporary fluctuations in industrial activity. A more effective solution would be to provide temporary work for the unemployed; not the digging holes and filling them up again solution of the classical economist, but useful work contributing to the area's amenities and improving its suitability for industry. The main requirement is for a source of capital to finance a variety of schemes within the competence of local authorities to supervise. Many skills could be employed, just as work has been found for the blind and the disabled. Instead of going on the dole, people out of work would go on the local authority's labour scheme, and employed on work related to their skills. Technically, they would still be unemployed, and would have to be relinquished for any suitable permanent work which turned up. Meanwhile, they would have a job to do. The task facing the managers of these schemes would be unusual but not impracticable—to employ a fluctuating labour force on productive work.

There are difficulties, certainly. But there were difficulties in finding work for the blind and the disabled. If an engineer has a structure which is highly stressed and cannot take an additional load, he carries the additional load on a different foundation, he puts it on a pontoon—any device to carry the load temporarily until the structure is modified or the external loads change.

Cover Picture.—*Three events dominate the engineering world this week. At Glasgow the British Association has been holding its annual meeting, and papers presented included discussions of radar aerials and radio telescopes; at Farnborough the SBAC is showing representative British aircraft, including the Victor; at Geneva the Second International Conference on the Peaceful Uses of Atomic Energy is presenting a three year harvest of nuclear work, and several papers have commented on fuel element design.*

* * *

Plain Words

Statistics—at least in their more advanced form—have never appealed to me very strongly. As a sampling technique, in the hands of an experienced operator, I am prepared to believe they are a most effective tool. Fortunately, statisticians, like the rest of us, can be made to toe the line: we can accept or reject their findings according to commonsense, inspired conjecture or—if we choose—just plain prejudice.

All this came to mind last week when Professor Saunders told a story in the middle of his presidential address to the Engineering Section of the British Association last week. His main theme was "Heat and the Engineer" and he had got around to that part of his paper which dealt with dimensional analysis. Then he described this gem of an experiment—it is not in the printed version of his address. On to a sheet of graph paper, with rectangular axes described as y and y_{not}, he had got someone to mark 100 random points. A second person was then invited to number these points from 1 to 100, again without order or pattern; these numbers were taken to be the values of a parameter, x. The data thus compiled could hardly have had more disjointed origins; the resulting "graph," thrown on the screen, was devoid of pattern, rhyme or *raison d'etre*.

Professor Saunders reported that he later took the x, y and y_{not} values for the 100 plots and calculated, for no other reason than to see what happened, x^2y and $\log_e x\ y_{not}$. He plotted these two quantities one against the other, and the resulting graph was exhibited on the screen. The new points defined a straight line as well as any set of experimental points are ever likely to define a straight line.

I believe I am right in saying that top mathematicians regard statistical theory with some degree of suspicion. The people at the meeting certainly relished Professor Saunders' story. I suppose it was akin to the fun we used to have at school when the boy who was always right was shown to be wrong. We are always afraid, too, of anything we don't understand: statistics have a disconcerting way of revealing truths which we think we could have discovered for ourselves. Maybe Professor Saunders should have called in a psychologist and the two of them tried to find a significant cause.

CAPRICORN

Weekly Survey

Noise from Jet Aircraft

A statement has recently been made by Mr. Harold Watkinson, the Minister of Transport and Civil Aviation, setting out the Government's policy on noise problems presented by the development of new large civil jet aircraft; problems which have already lost British European Airways the prestige of being the first airline to operate a direct service from Western Europe to Moscow. The Corporation had hoped to include a London-Moscow service in their 1958 summer programme, but they were prevented from doing so because the Ministry of Transport was unable to accept the noise level of the TU 104 jet airliner for scheduled services into London Airport. Meanwhile, Sabena started a Brussels-Moscow service with connections to London on 2 June last. Although people living in the vicinity of London Airport may well be grateful to the Ministry for the protection afforded by it, the Corporation have not unnaturally been concerned at the possible harm done to this country's position as one of the most important focal points of international air transport.

Mr. Watkinson's statement says that tests have shown that suppression in the case of the Caravelle and the Comet will reduce the impact of their noise so that it is comparable with that of piston-engined aircraft already in commercial use. Apart from these two aircraft, jet services into the United Kingdom in the near future have been planned by the TU 104 and the Boeing 707. The Soviet authorities claim to have developed techniques of operation which will reduce the noise of the TU 104 to that of existing piston-engined types and they hope that a proving flight may be arranged in the near future. In the case of the Boeing 707, it has been agreed that, subject to certain restrictions, which include operation in waking hours and in good weather only, Pan American World Airways shall bring one of these aircraft to London Airport in September, for a period of experiment and noise tests, and that these tests shall be followed by a period of crew-training flights, subject to such modified restrictions as the coming tests may show to be necessary.

Fuel Efficiency

The fourth annual survey of the National Fuel Efficiency Advisory Service, covering the year ended 31 March, 1958, shows a further rise of 22·5 per cent in bookings, compared with the year 1956-57, although the number of visits paid by the Service declined from 13,493 to 11,592. This position was mainly due to the nation's financial crisis, and to the mild weather during the autumn of 1957, which delayed the seasonal rise in bookings between September and November.

An interesting table in the report shows that the mean fuel saving obtainable from the 384 heat and power surveys carried out in 1957-58 was 21·5 per cent. The largest number of these surveys, 86, was made in the textile industries, where the mean saving was estimated at 22·5 per cent. The engineering and metal-working industries accounted for 40 surveys, with a mean saving of 19·6 per cent. These figures, however, tend to be overweighted by the results obtained in large firms, and thus to under-estimate the savings possible in the smaller and medium-sized factories. The total fuel consumption of works covered by the Service's heat and power surveys was more than 1,400,000 tons of coal per annum, or its equivalent in other fuels, and the report estimates the value to industry of the savings obtainable at £25 for each £1 paid to the Service in fees.

Doubts have been expressed from time to time, however, as to how far the recommendations made in the surveys are, in fact, implemented. As the report points out, it is very difficult to provide a final answer to this question. Information was collected regarding the fate of 347 recommendations made in 87 surveys. It was found that 75 per cent of the recommendations had been accepted and the work suggested put in hand, while action on another 9 per cent of the recommendations had been deferred until conditions were more favourable. A further 3 per cent of the recommendations were alternatives to accepted suggestions, and only 13 per cent of them had been rejected, not necessarily finally. If the selected sample to which these figures apply is truly representative, the result is a very satisfactory one.

The Service was originally set up with a guaranteed income to be provided jointly by the National Coal Board, the Gas Council and the Central Electricity Authority—now the Electricity Council—for a period of five years, which was to end in March, 1959. It is satisfactory to know that the guarantee has now been extended for a further five years; the National Coal Board accepting responsibility for a higher share than formerly of the guaranteed income. Contributions are also being made, on an annual basis, by Shell-Mex and BP Limited, Esso Petroleum Company Limited and the Government of Northern Ireland.

German Giants Still Growing

A recent report by the statistical office of the Federal German Republic shows that, in September, 1957, there were 92,000 industrial establishments in Germany. Of these, 2,467 have over 500 workers; 19,000 have from 50 to 500 workers; and the remainder, which come to well over 70,000, have less than 50 workers. These small firms have always made up three out of every four German firms. Their number has declined since 1952, but only by 4·3 per cent. The average number of workers employed by German industrial firms is 82 persons.

From the labour point of view, the position is that only 12 per cent of all workers are now engaged in establishments with less than 50 employees, and only 19 per cent of them are in factories with between 50 and 200 workers. Industrial establishments with more than 200, but under 500, operatives employ some 17 per cent of all workers. In fact, 51 per cent of all industrial workers are now in companies with payrolls exceeding 500 persons. Taking the main product groups, the statistics show that about one-third of German firms are engaged in the consumer-goods industries. These are followed by basic materials, machinery and consumer durables, food and kindred products, and mining, in that order.

Looked at from the point of view of the numbers employed, the order changes round and becomes: one, machinery and consumer durables; two, consumer goods; three, basic materials, steel, etc.; four, mining; and, five, food and kindred products. The backbone of German industry is still the small firm, but the tendency for very big organisations to grow up, especially in engineering, iron and steel, and mining, still remains one of the characteristics of the German industrial scene.

Scrap Policy Scrapped

Over the past five years the High Authority of the European Coal and Steel Community has operated a scheme for equalising the price of imported and home produced scrap. In the past year the fall in production of steel has cut down demand for scrap to a point where there is

not the same need to encourage imports. The High Authority has taken the opportunity to drop its subsidy policy and has reassumed powers which it had delegated to the Caisse de Péréquation des Ferrailles Importées at Brussels. Under the new arrangement firms are allowed to choose any six month period from their past three years activities as typical of their scrap consumption. A complementary levy is to be charged on scrap used above the figure for this selected period.

The change-over from a policy that, to put it no higher, did not discourage the use of imported scrap has a number of interesting features. One important reason for the old policy was the shortage of coke, but there also the position has eased. Another factor is the forecast of a shortage of iron ore by the years 1960-65. On this point the High Authority has advised firms to make long term contracts for ore supplies. It is on the planning side that the Community's scrap policy has produced its strongest reactions. Officials of the High Authority have watched with uneasiness the increase in open hearth and electric ore capacity called into being by the scrap policy. Strange stories are told of small electric furnaces using hydro-electric power operated by family teams headed by grandmothers producing steel up in the Italian hills.

At any rate, the High Authority is now going to control the building of new scrap-using plants. This will be done by persuasion, which can take the form of publishing an unfavourable opinion on a particular scheme, which means in practice that no bank will advance money for it. In other words, any firm that decides to go ahead with developments that do not meet with the High Authority's approval must do so out of its own resources.

Lower Output of Iron Castings

The Joint Iron Council recently issued a detailed commentary on the Iron and Steel Board's statistics for the production of iron castings in the second quarter of 1958. The total production, at 887,200 tons, shows a decline of 7·7 per cent compared with the first quarter of this year, and of 6·1 per cent compared with the second quarter of last year.

As compared with a year ago, the greatest decline occurred in the case of ingot moulds, mainly for the steel industry (15·2 per cent), and in building and domestic castings (14·3 per cent). Output for the engineering industry, including machine tools, textile machinery, electrical engineering and shipbuilding, accounted for 35 per cent of total production; and fell by 7·4 per cent compared with the second quarter of 1957. There was also a marked decline in the output of pipes and fittings for gas and water.

Overall decline in production would have been much greater had it not been for a strong demand for motor vehicles and railway equipment. Output for the motor industry, although below that for the first quarter of this year, showed an increase of 9·2 per cent compared with that for the second quarter of last year, and constituted an all-time second-quarter record. Production of castings for railway equipment rose by 5 per cent compared with last year, due to the needs of the railway modernisation programme.

As a result of the declining demand for castings, employment in the iron foundry industry fell by 4 per cent between June, 1957, and June, 1958. The consumption of pig iron fell by 11·5 per cent, nearly twice the fall in the output of castings, but this decline was to some extent counter-balanced by an advance of 9 per cent in the consumption of steel scrap. The Council's figures draw attention to the extent to which the present level of industrial activity is dependent upon the record level of output by the motor industry. Since the latter is now approaching the period of seasonal decline in production, a further fall in the demand for castings may be expected, unless there is a marked improvement in demands from other sections of the engineering industry during the coming autumn.

Concentration in the Motor Industry

In a paper read to the British Association on "Competition and Monopoly in the Motor Industry," Mr. Aubrey Silberston reaches the conclusion that, if the European Free Trade Area is formed, the British motor industry is likely to be in a strong position as long as careful attention is paid to the models produced and to sales policy. He foresees an intensification of competitive pressures and states that the competitive strength of the British industry would be increased if individual models of cars and commercial vehicles were produced on a larger scale. He suggests that this could probably be achieved most rapidly if further mergers between vehicle manufacturers were to take place. Such mergers would be unlikely to lessen competition appreciably and might reduce the costs of production a good deal.

In practice, the scope for further amalgamation is not very great since five manufacturers already account for 95 per cent of the cars made in this country and 80 per cent of the commercial vehicles. Two of these companies are United States subsidiaries and one of the uncertainties associated with the establishment of a Free Trade Area is how American companies, having a number of subsidiaries in Western Europe, are likely to react to it. This doubt, of course, affects a number of industries and it seems probable that there may well be some concentration of production by these American subsidiaries into those countries where production facilities are most favourable.

Whatever the method adopted, there will be little disagreement with the argument that, under the conditions to be expected in the Free Trade Area, the large-scale production of relatively few models is likely to show important advantages in lowering production costs. Moreover, with the enlargement of the market, the risks of specialisation will be correspondingly reduced, and it is possible that the ultimate result may be some degree of national specialisation within the Free Trade Area.

Through the Storm in Comet 4

Now well on the way to full certification for commercial operation, the de Havilland Comet 4 airliner has carried her first passengers, mainly members of the Press, among whom were a representative of ENGINEERING, and underwriters from Lloyd's. On the first demonstration flight, on 28 August, it seemed as though de Havilland and BOAC had specially laid on the weather in order to demonstrate the Comet's ability to ride safely and happily through violent storms. Perhaps conditions could have been worse: anyway, after waiting some 40 minutes listening to the crack and rumble of thunder, the clouds rolled off the airfield enough to make take-off possible. As the aircraft climbed away, the sky could be seen through the port windows, being rent by vivid lightning flashes. It was comforting to know that, forward in the cockpit, the cloud warning radar was picking out the "cu-nim" concentrations, enabling the pilot to guide the aircraft between the most severe storm areas, but the bad weather was so widespread that it was not possible to avoid entirely electrically-charged areas, and one quite sizeable discharge—a blue flash and a jolt to starboard—was noticed by some passengers.

Otherwise, had the curtains been drawn, the passengers would hardly have been aware of the weather outside (even without the champagne). Jet flight is not a new sensation, and the absence of vibration and general comfort of the Comet was what had been expected. But it had not been realised previously just how much the "bumps" are smoothed out of rough-weather flying by the swift-climbing Comet's fast passage through the storm gusts; and, at 35,000 ft, the aircraft was "above the weather" in brilliant sunshine.

Letters to the Editor

MIDDLE-AGED BACHELOR

SIR, I should like to endorse the leader in your issue of 22 August, calling for leave being given to senior staff for attending post-graduate courses to obtain a special B.A. degree.

I have long been of the opinion that it would be to the advantage of industry if it would release the senior staff on sabbatical leave at regular intervals; be it for travelling abroad to study developments in other countries, to take part in some special university courses, or just to relax and take stock of their achievements and to think of improvements away from their everyday tasks. It would give them the opportunity of reading up reports and technical and scientific papers, for which there is no time during the working year. This must surely lead to greater efficiency and be to the benefit of the firms concerned.

It would be a matter of course that the persons concerned would be reinstated in the posts vacated for the period of their leave, so that there would be no fear of their losing their positions. It would, though, give the junior staff an opportunity to show whether they were ready, if necessary, to take the place of the older or senior staff.

I can see no reason why the universities are not able to provide such courses, or why industry should not co-operate, and I hope that your idea, or something along these lines, will become a reality in the near future.

Yours faithfully,

K. R. LENEL.

2 Ballantrae House,
London, N.W.2.
25 August, 1958.

SIR, Your leading article, entitled "Middle Aged Bachelor," must have been of considerable interest to many, who, if like me, have just realised the need to resume a technical education, if only to discuss more intelligently problems relating to their work. Unfortunately, at forty, a period of twenty or more years has usually elapsed since any form of educational training took place, and it is during this period that "mental stagnation" has set in, each added year making it increasingly difficult to envisage further education, in spite of one's enthusiasm. Two years ago, my own enthusiasm, and need, for further technical learning prompted me to take a National Certificate course in engineering in the evenings. Egotistically, I had already decided that I had no need to attend the first, nor even second, year, but fortunately, a wisdom far greater than mine persuaded me otherwise. The first year proved a wonderful "rehabilitation" period, where I was taught once again the art of listening to and assimilating knowledge. The second year was exhilarating, and I am now even looking forward to my third year. This, then, is the "hard" way; three evenings a week, two and a half hours each evening, plus homework, varying in time according to one's capabilities.

Although your article has suggested a scheme of degrees for the older generation—a suggestion with which I wholeheartedly agree—I submit that one of the qualifications for entry to such a course should be a personal attainment in the nature of an engineering diploma or certificate obtained in later years. My reasons for this suggestion are twofold. Firstly, the individual must prove to himself that he is still capable of learning, and, secondly, it would enable the employer to judge the man's enthusiasm and ability. The work done by taking such a course would not be time wasted, if our universities would allow exemption from the preliminary work on a subject-for-subject basis.

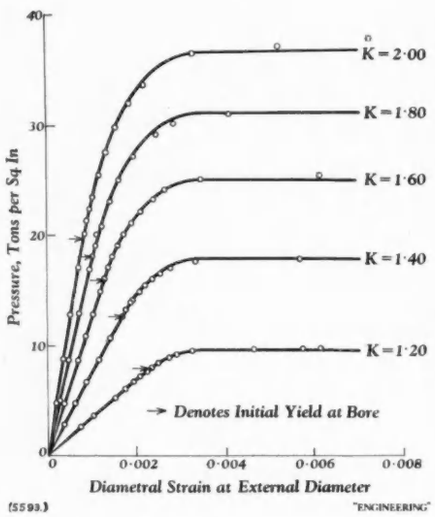
Enthusiasm for this scheme must be considerable among partly-qualified middle-aged men, and employers could not but benefit from its

Continuing Letters to the Editor

inception. It is to be hoped that the more enlightened and far-seeing of these will have read your illuminating leading article.

Yours faithfully,
J. H. L. BRIDGEWATER.

Avonside,
Hampton Lucy,
Warwickshire.
28 August, 1958.



Pressure tests on thick-walled cylinders. The permanent set which arises in the pressure expansion curve when the pressure is removed can be several times greater than the elastic strain at initial yield.

STRAIN HARDENING OF CYLINDERS

SIR, I should like the opportunity of replying to Dr. E. Voce's letter published in ENGINEERING of 1 August, page 131.

First, I cannot agree that "a cylinder is unlikely to dilate plastically until yield has reached the outer surface." If measurements of the diametral strain at the outer surface are made, then, as soon as yield occurs at the bore surface, there will be some departure from linearity in the pressure expansion curve and there will be a permanent set when the pressure is removed. By the time yield has reached the outer surface, this permanent set can be several times greater than the elastic strain at initial yield, depending on the diameter ratio (K) of the cylinder. This is clearly shown in the attached graph, which gives results obtained from pressure tests on thick-walled cylinders (for full details, see "Behaviour of Thick-Walled Steel Cylinders Subjected to Internal Pressure," *Proc. I.Mech.E.*, vol. 172).

Next, I think it is a purely arbitrary decision to define shear strain for the purposes of comparison with tensile strain, as indicated by Dr. Voce. If one assumes, however, that the work hardening is some function of the work done on the material, not an altogether unreasonable assumption, then it can be shown that $\sqrt{3}\,\gamma$ is the same function of tan ϕ (neglecting elastic quantities) as σ is of log l/lo, and experimentally this relationship has been demonstrated to hold for logarithmic strains of up to 0·2.

Though it is to be hoped that some firm experimental foundations can be established for the field of plasticity, this is bound to take a considerable length of time, and in the meantime it does seem much safer to base thick-walled cylinder results on shear properties derived from torsion. This has the added advantage that a torsion test is altogether simpler to carry out if properties at large strains are required, as in this particular problem.

Yours faithfully,
B. CROSSLAND,
Senior Lecturer.

Mechanical Engineering Department,
The University, Bristol, 8.
27 August, 1958.

PRINTING TRADE DIFFERENTIALS

SIR, In the paragraph "Clash over Craftsmanship" in The Human Element note published on page 199 of your issue of 15 August, the position taken up by this Society is badly misunderstood and I am sure you will take an opportunity of putting right the suggestion that this Society, in favouring a single-tier wages structure for the printing industry, seeks to do away with the craft differentials.

This is not the case. We accept that there are and should be craft and skilled rate differentials. We think that in a single wages structure, the relationship one with the other can be discussed and settled by all concerned.

Yours faithfully,
R. W. BRIGINSHAW,
General Secretary.

The National Society of Operative Printers and Assistants,
Caxton House,
St. George's Circus, London, S.E.1.
26 August, 1958.

The Valmet Straddle carrier described in our issue of 8 August, page 165, is powered by a Perkins P6 engine and not a P4 as was stated.

NOTICES OF MEETINGS

Association Sof upervising Electrical Engineers

LONDON
"Artificial Satellites and the International Geophysical Year," by Kenneth Ward. Central London Branch. White Hall Hotel, Bloomsbury Square, W.C.1. Mon., 8 Sept., 7.15 p.m.

BIRMINGHAM
"Navigational Aids," by C. Powell. Birmingham Branch. Birmingham Exchange and Engineering Centre, Stephenson Place, Birmingham 2. Wed., 10 Sept., 7.30 p.m.

CARDIFF
"The Diesel Engine as a Power and Heating Unit," by P. Makin. South Wales Branch. Angel Hotel, Cardiff. Tues., 9 Sept., 7.30 p.m.

GLASGOW
"Basic Principles of Nuclear Power Stations," by A. L. Shaw. Glasgow Branch. Institution of Engineers and Shipbuilders in Scotland, 39 Elmbank Crescent, Glasgow, C.2. Wed., 10 Sept., 8 p.m.

British Institute of Management

LONDON
Elbourne Memorial Lecture on "The Great To-Morrow," by the Earl of Verulam. Royal Commonwealth Society, Northumberland Avenue, W.C.2. Fri., 3 Oct., 8 p.m.

Electrical Industries Club

LONDON
"A Peep Behind the Iron Curtain," by W. H. L. Lythgoe. Luncheon Meeting. Connaught Rooms, Great Queen Street, W.C.2. Tues., 9 Sept., 12.30 for 1 p.m.

Engineers' Guild

LONDON
Annual General Meeting. Discussion on "The Changing Pattern of Leadership," opened by Mr. A. R. Cooper. Metropolitan Branch. Caxton Hall, off Victoria Street, S.W.1. Tues., 23 Sept., 6 p.m.*

Incorporated Plant Engineers

BLACKBURN
"Thermionic Power," by J. E. Read. Blackburn branch. White Bull Hotel, Blackburn. Thurs., 18 Sept., 7.30 p.m.

BRISTOL
Discussion on "Smoke Abatement and the Clean Air Act." Western Branch. Grand Hotel, Broad Street, Bristol. Wed., 10 Sept., 7.15 p.m.

COVENTRY
"Clean Air," by R. Williams. Birmingham Branch. Hotel Leofric, Coventry. Tues., 16 Sept., 7.30 p.m.

DUNDEE
Films and Discussion on "The Manufacture of Town Gas." Dundee Branch. Taypark Hotel, West Ferry, Dundee. Wed., 10 Sept., 7.30 p.m.

EDINBURGH
Various short talks by branch members. Edinburgh Branch. 25 Charlotte Square, Edinburgh. Tues., 9 Sept., 7 p.m.

MANCHESTER
Chairman's social meeting. Manchester Branch. Engineers' Club, Albert Square, Manchester. Tues., 9 Sept., 7.15 p.m.

NEWCASTLE UPON TYNE
"Site Casting and Steam Curing of Prestressed-Concrete Bridge Beams," by D. F. Lambkin. North East Branch. Roadway House, Oxford Street, Newcastle upon Tyne. Thurs., 11 Sept., 7 p.m.

ROCHESTER
Discussion on "A General Outline of Some of the Problems Involved in Space Travel." Kent Branch. King's Head Hotel, High Street Rochester. Wed., 17 Sept., 7 p.m.

Institute of Petroleum

LONDON
"Harmful Effects of Electrostatic Charges on Machinery and Lubricating Oils," by Dr. T. Salomon. Wed., 17 Sept., 5.30 p.m.*

Institution of Production Engineers

LONDON
"The 1960 Associate Membership Examination and Its Implications," by F. W. Cooper. London Graduate Section. Wed., 10 Sept., 7.15 p.m.

BIRMINGHAM
Various short technical films. Birmingham Section. College of Technology, Gosta Green, Birmingham. Wed., 17 Sept., 7.30 p.m.

NORWICH
Discussion on "Material Control Progress and Machine Loading." Norwich Section. The Assembly House, Norwich. Wed., 10 Sept., 7.30 p.m.

SHREWSBURY
Film on "Copy Turning." Shrewsbury Section. Technical College, Shrewsbury. Wed., 24 Sept., 7.30 p.m.

WOLVERHAMPTON
"Engineering Metrology," by J. R. Adams. Wolverhampton Graduate Section. Wolverhampton and Staffordshire College of Technology, Wulfruna Street, Wolverhampton. Wed., 17 Sept., 7 p.m.

Modular Society

LONDON
Discussion on "Modular Assembly After Its Erection," and a display of drawings. Building Centre, Store Street, W.C.1. Wed., 24 Sept., 6 p.m.

Society of Chemical Industry

NEWPORT
"Some Factors Affecting the Performance of Condenser and Heat Exchanger Tubes," by Dr. P. T. Gilbert. Corrosion Group. Joint meeting with the South Wales Section of the Society and the Cardiff Section of the Royal Institute of Chemistry. King's Head Hotel, Newport, Monmouth. Tues., 16 Sept., 7 p.m.

Society of Instrument Technology

BIRMINGHAM
"Fuel Efficiency and Smoke Abatement," by C. A. J. Plummer. Midland Section. Regent House, St. Phillip's Place, Colmore Row, Birmingham 3. Fri., 12 Sept., 7 p.m.

GLASGOW
"Circuitry of a Typical Digital Computer," by F. Bailie. Scottish Section. Scottish Building Centre, 425 Sauchiehall Street, Glasgow. Fri., 19 Sept., 7.15 p.m.

NOTTINGHAM
"Instrumentation in the Hosiery Industry," by D. L. Munden. East Midland Section. Nottingham and District Technical College, Shakespeare Street, Nottingham. Thurs., 18 Sept., 7 p.m.*

The address and telephone number of the headquarters of each institution are given below. Meetings in the headquarters town are held there unless otherwise stated. Particulars for this column should reach the Editor not later than three weeks before the date of the meeting.

* An asterisk is placed where it is understood that refreshments are available prior to the time stated.

Association of Supervising Electrical Engineers, 23 Bloomsbury Square, London, W.C.1. (LANgham 5927.)
British Institute of Management, Management House, 80 Fetter Lane, London, E.C.4. (HOLborn 3456.)
Electrical Industries Club. Apply to Mr. A. S. Lowe, Magnet House, Kingsway, London, W.C.2. (HOLborn 4538.)
Engineers' Guild, 78 Buckingham Gate, London, S.W.1. (ABBey 7315.)
Incorporated Plant Engineers, 12 The Parade, Solihull, Warwickshire. (Solihull 1111.)
Institute of Petroleum, 61 New Cavendish Street, London, W.1. (LANgham 3583.)
Institution of Production Engineers, 10 Chesterfield Street, London, W.1. (GROsvenor 5254.)
Modular Society, 22 Buckingham Street, London, W.C.2. (TRAfalgar 4567.)
Society of Chemical Industry, 14 Belgrave Square, London, S.W.1. (BELgrave 3681.)
Society of Instrument Technology, 20 Queen Anne Street, London, W.1. (LANgham 4251.)

Companies in the News

Green's Economiser

One of the oldest of the large private companies, E. Green and Son Limited, made a public issue last week. In many respects this is a remarkable concern: the business was founded in 1826 by Edward Green who was the great-great-grandfather of the present chairman, Mr. Simon Lycett Green and of Sir Edward Lycett Green. In 1945 the founder invented the original "Green's Economiser," claiming to have discovered "a new method of economising fuel and certain improvements in retaining and applying heat for generating steam and heating water," by using the waste heat from boiler flues. Fuel economisers still account for over 90 per cent of the company's output. They have grown to a substantial size, with net assets totalling £2·7 million at the end of last year and trading profits of £486,000 for the year ended 31 December.

Over the past few years, the company have followed a policy of diversification and now manufacture in addition to fuel economisers various other types of heat exchangers such as heating coils for oil tankers and air heaters, industrial dust collectors and mechanical draught fans. The works at Wakefield are equipped to deal with steel fabrication, pipe work and pressure vessels. The company have for a very long time operated on an international basis, with a manufacturing subsidiary in France and marketing subsidiaries in South Africa, India, Canada and the United States. In addition the group comprises three United Kingdom subsidiaries, J. W. Harrison, who own a foundry in Wakefield, Johnson Bramley and Company Limited and Eco Power. Total employment was approximately 1,360.

The reason for making a public issue was not the need for more working capital (ample reserves exist). The problem of death duties was doubtless the principal factor and in this respect Greens have followed the example of practically every large private company in the country (Rubery Owen and Ferranti being two notable exceptions).

John Brown's Progress

The progress of the John Brown group has continued, in established products as well as in new fields. Last year's profits, for the twelve months ended 31 March, totalled some £3·3 million, about £100,000 more than for the previous year. Nonetheless, Lord Aberconway, the chairman of the group recently foresaw some trouble spots ahead. He sounded "various notes of caution" and made some suggestions, in respect of depreciation allowances, which might improve the situation of shipbuilding and heavy engineering. His concluding remark to his shareholders was that, by and large, the board of directors was confident that, given reasonable trading conditions, the company could meet whatever was in store.

Shipbuilding had kept up remarkably well. In Lord Aberconway's view, "undue significance has been attached in some sections of the Press to adjustments in the building programmes" of certain of the group's clients. Cancellations had been few and had had little impact. British shipowners "may be congratulated on the robustness of their long-term view." One developing weak spot was in the land boilers division. The future of this business, Lord Aberconway considered, must be viewed with anxiety. Overseas competition was intense and prices unremunerative. The nuclear programme at home had reduced requirements for new thermal plant and the increase in the size of thermal units had severely limited the number of boilers that would be needed every year. The fact that the John Brown group had started this activity at the request of what was then the British Electricity Authority, was recalled without comment.

On the nuclear-engineering side, John Brown's activities—jointly with the Hawker Siddeley group—have led to the conclusion that a cautious approach is needed. Lord Aberconway said that, to enter the field of design of nuclear reactions was a costly operation, by no means certain to be crowned with success. The group's machine-tool company, Wickman Limited, in common with the rest of the machine-tool industry, have experienced a fall in orders. They have delivered many more automatic lathes than they have received orders for, although their tungsten-carbide products continue to compete successfully. Other companies, Cravens, who build carriage and wagons; S.N. Bridges, who make electric tools; Constructors John Brown, who are developing fast in the chemical industry, have all done well and have good prospects. But, overall, there is increased competition for a smaller amount of business. Hence Lord Aberconway's plea for "fair and proper depreciaction allowances, based on replacement, not original cost" in which he makes a strong case for a new conception of industrial investment. This suggestion, if adopted by the Treasury, could transform the prospects of capital goods manufacturers.

Testing Time for Special Steel

"Unity, leadership and courage" are the need of the present day, according to Mr. W. H. Higginbotham, the chairman of Edgar Allen and Company Limited. He was discussing the prospects of his company and the industry of which it forms a part, following upon a most successful trading year, which ended on 29 March last. During this period, group sales rose by 6 per cent; while profits were increased by 18 per cent, to a total of £780,000 before tax. Mr. Higginbotham spoke at length on the many factors involved in assessing the future, saying that, outstanding among them was the threat of re-nationalisation, which they would fight "by all legal and practical means." He also reviewed the economic situation, finding little there to be cheerful about. Falls in commodity prices, he said, had reduced the purchasing power of Britain's leading markets and the course of the trade recession in the United States remained uncertain. In general, he found the international situation "menacing" and the future "uncertain and dangerous."

The detailed analysis of current trends for each of the group's products showed that in practically every case there had been a considerable reduction in the value of unexecuted orders; tools being the only major exception. There had also been a partial recovery in the orders for steel, which had continued during the current year. Steel castings suffered heavily at the beginning of the year, but the fall has been arrested and the present trend was upwards: much now depended, however, "on the maintenance of stability in material prices and wage rates." Prospects for engineering products—affected by the Middle East crisis—were now much improved. Unless these improvements were continued and the rate of recovery stepped up "the trading of the current year might be adversely affected."

A similar attitude was taken by Mr. Ronald Hampton, the chairman of the Union Steel and Manufacturing Company Limited, which makes bright steel bar, nuts, bolts, screws and other bright steel products. "I cannot forecast any easier time for us workers," he said, "or more lucrative returns for the investor." But this, he suggested was not perhaps a bad thing. Even if the industry has come to the end of the present round of rapid expansion, it can still face the future with confidence, provided that the qualities specified by Mr. Higginbotham are in abundant supply.

Fanning the World

One of the largest and oldest-established firms of fan makers in Europe, Keith Blackman Limited, have experienced a very satisfactory period of trading, for the year ended 31 March last, having increased their trading profits from £388,000, in 1957, to £469,000. Looking ahead, their chairman and managing director, Mr. Donald S. Woodley, has expressed the view that there is "no reason to anticipate any fall" in the demand for their products and that, therefore, full-capacity production is likely during the current year. The fact that industrial fans are used very widely—almost as a general engineering component—makes such a statement as Mr. Woodley's particularly valuable as a guide to the pattern of activity in the engineering industry as a whole. He sounded a note of caution as to the outlook further ahead, however, saying that there was an "absence of any very reassuring signs of the attainment of real industrial stability" but adding that he saw no cause for alarm, or any immediate likelihood of a decline in the level of activities.

Steady Current

The vast expansion of electrical engineering over the past 50 years is excellently illustrated by the progress of Ferranti Limited, still a private company under the chairmanship of the founder's son, Sir Vincent de Ferranti. The company was formed in 1882 as Ferranti, Thompson and Ince to manufacture an alternator and electricity meter developed by Sir Vincent's father. They now have, in their 75th year, a turnover of £24 million (including £8½ million direct exports), an order book of £22½ million and a capital employed of £13 million. Trading profits for the group last year (to 31 March) totalled £1·25 million. The products include a wide range of power transformers, electronic digital computers, semi-conductor devices, cathode-ray tubes, metal-to-ceramic seals, electricity meters and electrical measuring instruments, radio and television, radar and guided missiles.

Ferranti are among the industry's leaders in electrical and electronic control equipment and their expansion in recent years has been considerable in this field. But, as Sir Vincent de Ferranti points out, it has not been a walk through: "we have survived," he said, "in spite of many vicissitudes, particularly at the start of this century when foreign competition, notably in Germany, had unrestricted access to our markets, which were also subjected to severe competition from wholly-owned subsidiaries established in this country by large American concerns."

Other annual reports of electrical engineering concerns suggest continued confidence in the long term demand for the industry's products. But there is some apprehension concerning the more immediate future. Mr. Charles Reid, chairman of Electric Construction Company, speaks of "increased competition," despite which his company enjoyed good trading conditions (profits were slightly higher, at £230,000, than the previous year). They have a substantial order book and expect to continue to do well. Mr. Jules Thorn, on the other hand, was unable to forecast such a smooth passage for Thorn Electrical Industries. He considers his company "well-equipped to meet prevailing conditions" but does not feel "optimistic pronouncements" would be justified at the moment. Thorn's profit growth has been rapid and uninterrupted —from £93,000 in 1947 to £1·46 million last year—and Mr. Thorn's outlook is on the whole more cheerful than that of his colleages in the electrical appliance, radio and television industries.

Special Articles

LUNAR PROBE PATHS FOR APPROACHING THE MOON

By G. V. E. Thompson

On August 17 the first U.S. lunar probe, *Able I*, was launched from Cape Canaveral, Florida. After rising steadily it began its planned turn towards the north-east. Observers thought that it was going well and that the puff of smoke emitted was caused by the second-stage engine taking over. However, it was the result of an explosion in the first stage and the vehicle turned downwards and crashed into the Atlantic Ocean 10 miles north of its launching site. The experiment was not a complete failure, in that the telemetering system continued to transmit data for a minute after the explosion.

The launching was carried out by the U.S. Air Force, and the space test vehicle employed was built up from a Douglas *Thor* IRBM, with a modified Martin *Vanguard* as second stage, and a new solid propellent third stage. The *Thor Vanguard* (*Thor-Able*) combination has previously been used in the re-entry test vehicle programme. The satellite payload carried by the third stage weighed 85 lb and included a simple form of television camera. Preparing the vehicle for launching took seven hours (one report stated that 300,000 parts had to be checked), but the firing was only four minutes late, and this delay was caused by unidentified radio interference. The vehicle reached a height of 50,000 ft.

In an effort to minimise the bad publicity that might follow a possible failure there were few official announcements before the launching. Nevertheless, the approximate date had been known for some months, and a series of " leaks " ensured that by the time the attempt took place a world-wide audience was awaiting the outcome. The disappointment of the USAF team will be shared by many, but is tempered by the thought that this is but the first of several tests.

Although no information is available concerning the cause of the failure, it occurred so early during the ascent that it gives no indication of the chances of success in future attempts. Official estimates are about 1 in 10, but that may be over-optimistic. The failure merely emphasises the well-known fact that the complex liquid propellent rocket offers many more opportunities for mishaps to occur than does the solid-propellent rocket. But even if the vehicle had functioned perfectly, the chances of the objective being successfully reached were not high. The harvest moon in the sky may seem quite a large object, but hitting it with a rocket is not as easy as hitting a street light with an air gun.

Actually, hitting the Moon in the present experiments is undesirable. Although there have been suggestions that a nuclear warhead should be exploded on the surface of the moon (Professor S. F. Singer[1] of the University of Maryland has suggested that dust from such an explosion would be carried into the Earth's atmosphere and might enable us to determine the composition of the lunar rocks), there are good scientific reasons why this should not be done. The absence of all but a most tenuous atmosphere, coupled with the low gravity on the Moon, would mean that dust from an explosion would be scattered over a vast area of the surface. It might subsequently be difficult to distinguish between the natural and man-made radioactivity. In addition, interesting selenological features might be destroyed and the atmosphere seriously contaminated. The landing of an instrument probe on the surface might do little damage, but more useful information can be obtained initially by an orbit around the Moon. A mechanical television scanning system has been developed, at a cost of 200,000 dol, by the Naval Ordnance Test Station at Inyokerm, California, and it is hoped that this will enable us to obtain the first pictures of the " other side of the Moon." The Moon rotates once about its axis in exactly the same time as it moves once around the Earth, and thus it always shows the same face towards us (owing to its librations, or oscillations, some 60 per cent of its surface can be seen at one time or another). Subsequent United States probes will carry such equipment as a camera with device for electrical transmission of the photograph, and a magnetometer for measuring the extent of the Earth's field and for detecting the Moon's magnetic field (if any).

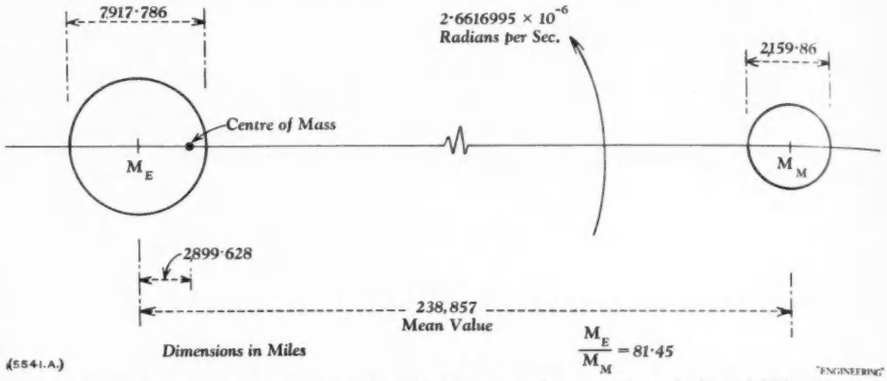


Fig. 1 The Moon and Earth rotate about their centre of mass, situated about 3,000 miles from the Earth's centre.

There are two possible types of orbit near the Moon which would permit obtaining useful information with these instruments. If the probe passes fairly close to the lunar surface and is not then travelling at too high a velocity it will be captured by the Moon's gravitational field and become an artificial satellite of the Moon. The absence of an atmosphere would enable the satellite to orbit almost indefinitely and if provided with solar or nuclear batteries it could supply data concerning lunar phenomena and its own perturbations for a considerable period. If the probe arrives with a high velocity or at an altitude of more than about 2,000 miles it would probably not make even a single orbit around the Moon, but would merely curve in past it and then shoot away into space, either to return towards the Earth, or (more likely) to become a minor asteroid in the solar system.

The possibility of a probe orbiting the moon is greater than that of hitting it, but is still quite slender. This can be seen by considering the behaviour of the Earth-Moon system. As is shown in Fig. 1, the diameters of the two bodies are about 8,000 and 2,000 miles respectively, the mass of the earth is about 80 times that of the Moon, and acceleration due to gravitation at the Earth's surface is about six times that at the lunar surface. The distance between the centres of the two bodies is about a quarter of a million miles (owing to the eccentricity of its orbit, the distance varies from 221,463 to 252,710 miles).

The Moon is different from the satellites of other planets in the solar system in that it is too large to be considered to revolve around the Earth's centre. The two bodies rotate around their centre of mass, which is situated about 3,000 miles from the Earth's centre along the Earth-Moon axis. The gravitational attraction of the Earth gradually decreases in passing along this axis until it equals the Moon's pull at about nine-tenths of the way along. Beyond that point the Moon's pull predominates.

The path of the probe can be elliptical or parabolic, as in Fig. 2, depending on its velocity on separating from the launching vehicle. The most economical path would be an ellipse just grazing the Moon's orbit; for higher initial velocities, the ellipse or parabola would intersect the Moon's orbit; for lower velocities it would fall short of the orbit. At high parabolic velocities the probe would be likely to be travelling too fast to be retained by the Moon's gravitational field, although it would be possible for it to score a direct hit. The grazing ellipse necessitates a journey time of about five days, a parabolic orbit only about 50 hours or less. At the time of writing, reports indicate that *Able I* would have taken about 2½ days.

The Moon being a moving object, it is necessary to ensure not only that the paths intersect or touch, but also that the initial configuration is such that both probe and Moon arrive at the point of intersection at the same time. No correction can be made to the path of the probe once it has left the launching vehicle. It will be evident that not only must the path of the Moon be known with accuracy and the initial velocity given to the probe be controllable within narrow limits, but it must also be possible either to launch the vehicle at the predetermined time or to apply the necessary corrections to the course in the event of any last minute delay in firing.

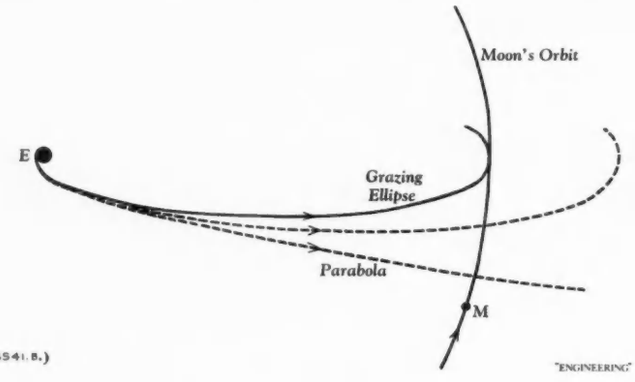


Fig. 2 Various paths of approach to the Moon are possible for a lunar probe.

A four minute delay might mean a few hundred miles difference in the position of the Moon when the probe reaches its orbit.

In any calculation for an actual launching, various other factors must be considered. These include the gravitational field of the Sun and the effect of the Earth's oblateness. If the probe becomes an artificial satillite of the Moon it may do so in either a direct or retrograde orbit. Published literature on the dynamics of flight to the Moon includes papers by Porter,[2] Egorov,[3] [4] and Buchheim.[5]

The optimum time and date of launching of a lunar probe depends upon the type of experiment being conducted, e.g., whether a scan of the "facing side" or of the "other side" is required. Conditions similar to those of last Sunday will arise about a month later, so that another launch might take place on 14 September. However, it is quite possible that other probes might be launched in the meantime. The United States Army is preparing another type of lunar probe, consisting of a Chrysler *Juno II* (*Jupiter*), with three Sperry *Sergeants* for the second stage, and a single *Sergeant* for the third stage.

Lunar probes form only one aspect of a comprehensive programme of space research. In the United States, work on a nuclear-propelled rocket is said to have reached the engine test stage; electrical propulsion is also being investigated. Flights in the first manned re-entry vehicle (the North American X-15) should take place early in 1959. Considerable research into the physiological and psychological problems associated with man's survival in outer space has already been carried out. Although little information is available, there is no doubt that parallel developments are taking place in the Soviet Union. If Britain is to enter the "space race," it will not be enough just to contemplate putting up a sputnik or two: that would be both too little and too late. Although satellites will continue to be launched, they will soon be playing only a minor part in astronautics. Our participation, even as part of a Commonwealth or European group, will be very expensive, but can we afford to stand aside from this rapidly developing field of research?

Opposition to Britain's participation in space research does not come from the man in the street, but rather from certain scientists (rarely engineers) who begrudge money spent thereon. This parochial attitude is typified by the reported comment of the Royal Observatory on the launching of *Able I:* "there goes money which might better have been spent on a telescope."

REFERENCES

[1] S. F. Singer, paper presented to VIIIth International Astronautical Congress, Barcelona, October, 1957.

[2] J. G. Porter, *J. Brit. Interplanetary Soc.*, 1952, vol. **11**, 205-210.

[3] V. A. Egorov, *Doklady Akad. Nauk S.S.S.R.*, 1957, vol. **113**, 46-49.

[4] V. A. Egorov, *Uspekhi Fizicheskikh Nauk*, Sept., 1957, vol. **63**, Supplement 1a, 73-117; paper presented to VIIIth International Astronautical Congress, Barcelona, October, 1957.

[5] R. W. Buchheim, *RAND Report P-873*, June 14, 1956; paper presented to VIIth International Astronautical Congress, Rome, September, 1956.

Following the Probe

The radio telescope at the University of Manchester's Jodrell Bank experimental station will be used to track the lunar probes under schedule for launching from the United States. Being fully steerable, the telescope is able to follow any probe throughout most of the time that it is above the horizon. The lunar probe carries a small transmitter, and the function of the radio telescope is to receive the signals that are emitted. There are two aspects. First the telescope will give the bearing of the lunar probe in space. However, it will not be possible to give other than a rough approximation of the probe's position from Jodrell Bank—the exact position will be worked out by computer in the United States from data teletyped there. The second function of recording the signals is to pick up the telemetered information, that is, the scientific measurements made as the probe approaches the Moon. These data will also be sent to the United States.

The advantage of using the radio telescope is that it has very great sensitivity and can therefore pick up weak signals at great distances; also, the beam width of the telescope is small enough to allow the position of the probe in the sky to be determined with considerable accuracy.

If the probe goes off course, the advantage of using the big telescope at Jodrell Bank is great. For if the probe does go out into space, it should be possible to track it for one million miles or so. It is likely that the batteries in the probe would fail before it got out of range of the telescope.

Professor A. Lovell was invited some time ago to take part in the United States lunar probe project; although this work is not the primary object of the radio telescope, the professor was delighted to co-operate. A team of research workers with special equipment was sent from the United States to assist at Jodrell Bank.

Professor Lovell and his second in command for this work, Dr. J. G. Davies, have been in Moscow attending the meeting of the International Astronomical Union. Commenting on the lunar probe experiment, before leaving for Moscow, Professor Lovell said: "This is another enormous step forward into the investigation of space by satellite vehicles, and eventually, we hope, by manned vehicles. This experiment will show that it is possible to begin to think of getting quite complicated and large scientific instruments to considerable distances above the atmosphere of the Earth. In this special case of the lunar probe there are many facts which one would like to know about the lunar surface, the magnetic field of the Moon, and so on. To me, at least, it is a mere stepping stone to the future investigations when we succeed in getting similar probes many many millions of miles into space so that one can explore the atmospheres of the planets, and perhaps get more information about their surfaces."

ATLAS PROPULSION SYSTEM

The propulsion system for the 15,000 m.p.h. U.S. Air Force-Convair Atlas intercontinental ballistic missile is the most powerful system in the free world to enter flight test and production. Shown in the illustration on this page, it can be seen to be a cluster of liquid-propellent rocket engines, comprising a twin-chambered booster engine and a sustainer engine for high-altitude efficiency; the system is completed by two small stabilising engines.

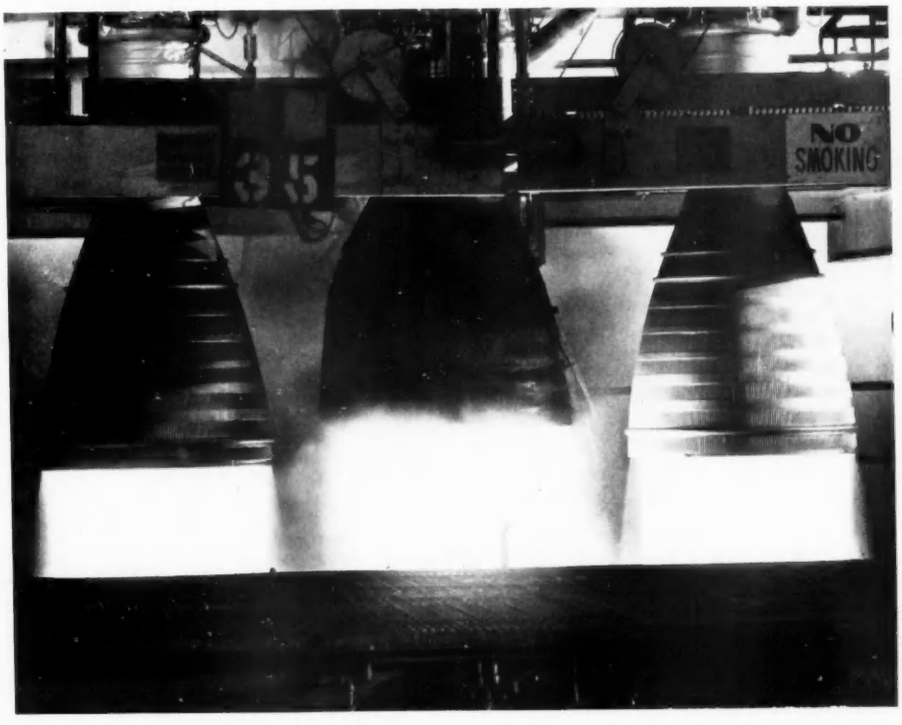
The system was designed and developed for the Atlas missile by Rocketdyne, a division of North American Aviation Incorporated, and is in production at the division's main plant in Canoga Park, California, USA. The complete propulsion system, including sustainer, had been thoroughly ground tested by Rocketdyne and Convair for a year and a half before entering flight test this year.

Each rocket engine in the Atlas propulsion system is designed to perform a specific job. The twin-chambered booster engine provides high thrust to lift the heavy missile from its launching site. It is jettisoned after operating for its programmed duration, when it has boosted the Atlas to high speed and high altitude. The single-chambered sustainer, designed for efficient high-altitude performance, supplies the slightly lower thrust necessary to sustain powered flight.

Directional stability of the missile is maintained by swivelling the large engines of the propulsion system on gimbals—a part of their assembly—and moving them by struts actuated by the guidance equipment of the missile.

Roll control is provided by the propulsion system's vernier, or stabilising, rocket engines, small auxiliary units for precise thrust adjustments. They are mounted on the side of the missile and are also gimbaled for movement.

All engines of the Atlas propulsion system develop thrust from the propulsive gases created by the combustion of liquid oxygen and RP-1, a hydro-carbon fuel similar to that used in turbojet engines. Combustion occurs at temperatures above 5,000° F. The thrust chambers of the engines are cooled by RP-1 fuel forced through their hollow walls and into the combustion area by the engine's high-flow turbo-pump.



The propulsion system for the Atlas ICBM comprises a central sustainer rocket engine and a twin-chambered booster engine, together with two small stabilising engines. Liquid fuel is used.

Design

JET TRANSPORT PROJECT WITH BOUNDARY LAYER CONTROL

Two new transport aircraft projects have been announced recently by Handley Page Limited, London, and are featured on the firm's stand in the static exhibition at Farnborough. The H.P. 111, or Treble One, details of which have been put forward to the Royal Air Force, is a large military transport aeroplane, the design of which is based on that of the Victor bomber. The other aircraft, the H.P. 113, is a small jet airliner of the executive class which has been conceived as " a research vehicle for demonstrating the practical feasibility of the laminar-flow technique for application to long-range aircraft." Handley Page, who have for many years been working on the application of boundary-layer control to the reduction of drag resistance, are going ahead with the construction of this most interesting venture.

The layout of the H.P. 113 is shown in the illustration on the right. It will be powered by two Bristol Orpheus turbojets. Two four-stage axial-flow compressors, driven from the main aircraft engines, are used to suck some of the turbulent boundary-layer air from the wing and tail surfaces in order to maintain laminar airflow. Over most of the surface area, the air is sucked through machined slots. On the leading edges and wing access doors, porous steel is used. An automatic " blowing " system is used for delaying the onset of stall on the ailerons and rudder when manoeuvring at low flight speeds.

In comparison with a conventional airliner of the same payload capacity and external form, the makers state, the range capability of the H.P. 113 is increased by over 60 per cent. Moreover, the reduction in wing drag allows the use of a lower wing loading than is customary on an aircraft designed to cruise at nearly 530 m.p.h., and, hence, the H.P. 113 should be able to operate from moderate-size airfields.

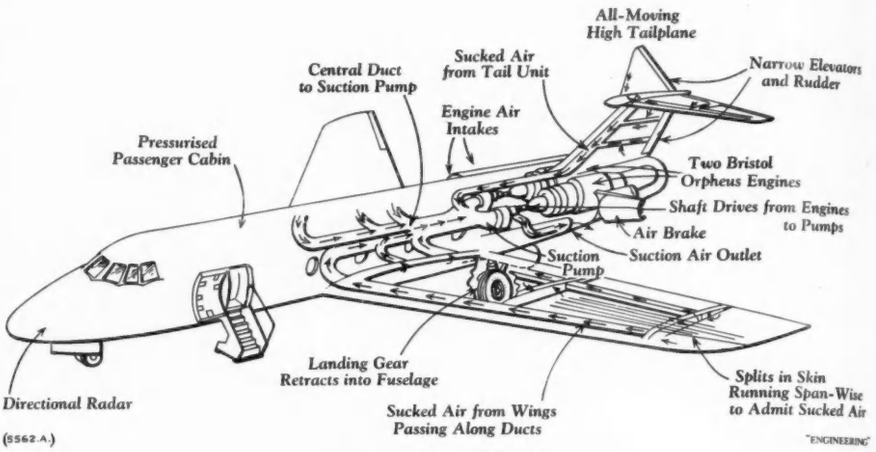
The principal particulars and estimated performance of the H.P. 113 are as follows: length, 71½ ft; height, 17 ft; wing span, 71½ ft; wing area, 775 sq. ft; aspect ratio, 6·6; sweep-back, 35°; passenger cabin volume, 900 cu. ft; maximum payload, 2,520 lb; and fuel capacity, 2,290 gal. At the maximum design take-off weight, 36,500 lb., the H.P. 113 will take off from sea level and clear 50 ft in a distance of 3,260 ft (ambient temperature 15° above international standard conditions).

With maximum payload, the aircraft can operate over a stage length of 3,640 miles (London-New York is 3,440 miles); and with a 1,000 lb payload, over 4,330 miles.

THE TREBLE ONE

The Treble One general-purpose military transport aircraft is shown in model form on Handley Page's stand. This aircraft is intended to combine the roles of fast intercontinental heavy transport, and of tactical freighter and paratroop carrier. The aircraft could be quickly built, since many of the main components are identical with those of the Victor.

The Treble One military transport aircraft is largely based on the Victor airframe, but has Conway engines and " blown " flaps for low-speed manoeuvrability.



Layout of the H.P. 113

It is powered by four 17,250 lb thrust Rolls-Royce Conways. With a maximum payload of nearly 27 tons, its range is 3,800 miles at a cruising speed of 545 m.p.h. The maximum take-off weight is 240,000 lb; in the tactical role, with its take-off weight restricted to 180,000 lb, the aircraft could operate from short roughly-prepared air strips.

The Treble One differs from the Victor mainly in the flaps, which are of larger area to improve low-speed manoeuvrability, and are " blown." It is also different in the air-conditioning system, which has to serve a large cabin instead of a small crew compartment; and in the fuel-proportioning system which automatically balances the tank contents as fuel is used. Almost identical with those of the Victor are the wing and tail structure, flying controls, yaw and pitch autostabilisers, electrical circuits, fuel venting and pressurisation.

The fuselage arrangement is as follows: behind the crew quarters and space reserved for aircraft equipment is an upper-deck cabin, usually seating passengers, below which is a freight hold. Aft of this, there is a hold 40 ft long, 11½ ft high and 11½ ft wide (maximum). This hold can be either single-deck, for heavy loads, or two-deck for lighter cargoes and personnel carrying. The upper-deck main floor is detachable and, handled by the freight hoists, is readily attached to the lower floor. The usual ramp cargo door could be fitted at the rear of the hold.

LIQUID COOLING FOR AIRBORNE RADAR

Future trends in the aircraft industry are often foreshadowed by the exhibits on the Ministry of Supply stand at Farnborough. Possibly the most interesting item this year is the display of liquid-cooling systems for airborne radar equipment, developed by the Royal Radar Establishment.

At present-day flight speeds, adiabatic heating of the air in and around the aircraft adds to the problem of cooling the electronic equipment efficiently—a problem which has to be considered at the aircraft design stage. Hitherto, the waste heat from the electronic equipment was rejected to the air—but at supersonic speed the latter is no longer economically suitable, either as a heat transporter or as a low-temperature heat sink. Liquid cooling offers an efficient means of meeting the primary problem of transporting waste heat away from the electronic equipment; a rejection heat exchanger must necessarily be provided as an aircraft service.

Various techniques in the application of liquid cooling are being explored at the Establishment. Some early experimental examples, showing an integral chassis dissipating heat in insulated and sealed containers, are exhibited, as well as a fabricated soldered-tube unit.

The Establishment's work is concerned only with techniques in which the chassis itself is the heat exchanger. The disadvantages of this system seem to be confined to the risks of leaks and some loss of flexibility in the experimental construction of prototype units.

The advantages which may be expected from liquid cooling, which is the only practical way yet known of cooling electronic equipment in aircraft having speeds much higher than those of to-day, are a reduction in aircraft fuel load due to the weight saving in ducting, air blowers, drag, and generator capacity; greatly improved heat-transfer characteristics, particularly since heat can be removed by the coolant virtually at its source; improved reliability due to operation within much narrower temperature limits than hitherto; and the possibility of greater thermal loading. Thermal segregation is more readily achieved, and the power expended in the coolant circulation is a very small fraction of that required in some air systems. Small bore pipes are used, instead of large-section ducting; and no special maintenance difficulties are involved.

Two integral chassis materials currently being investigated are an electroformed seamless nickel honeycomb with walls about 0·01 in thick, and a recently-available commercial aluminium ducted sheet. A chassis made in either of these materials is housed in a pressure-tight container; heat transfer to the chassis from the electronic components is primarily conductive and convective.

The coolant is circulated on a closed system by a pump from a reservoir tank to the electronic equipment, thence to the rejection exchanger and back to the tank.

Ancillaries necessary for a liquid-cooled system are quick-release self-seal couplings on flexible hose; a circulation pump; a sealed reservoir tank fitted with constant pressure relief valves; a simple by-pass temperature controller; means of insulation to restrict the flow of heat from the aircraft into the electronic equipment; a coolant which is mobile from − 60° C to + 120/150° C, which is compatible with the materials used, and of low hazard.

To be seen at Farnborough

DEVELOPMENTS IN ELECTRONICS AND INSTRUMENTS

Transistorised equipment, used generally in conjunction with printed circuits, is not only making possible considerable savings in space, weight and power consumption, but is also reducing the problem of cooling electronic equipment at very high altitudes and is leading to greater reliability of the equipment. Among the many firms at the Society of British Aircraft Constructors' exhibition showing transistorised components and systems, E. K. Cole Limited, Southend-on-Sea, announce a new range of transistor inverters providing a 400 cycle supply from a 24 V direct-current output—two 115 V single-phase inverters rated at 75 VA and 175 VA, respectively, and two three-phase inverters, rated at 225 VA and 500 VA, respectively, and providing either 115 V or 200 V supply. Pye Telecommunications Limited, Cambridge, are showing a new overspeed and rotation indicator, developed for the Rolls-Royce Conway engine, which they believe to be the first application of transistors in airborne control equipment. The only moving equipment is a small tacho-generator mounted on the jet engine; warning of overspeed is indicated on the pilot's or flight engineer's panel by a flashing light. The instrument uses potted component "bricks" on printed-circuit bases for increased reliability, reduction in weight, and ease of manufacture.

New transistorised airborne radio equipment, which makes use of printed circuits, is displayed by Standard Telephones and Cables Limited, Aldwych, London, W.C.2. The new equipments include a comprehensive VHF/ILS/VOR equipment (STR 23/34/35/36); transistorised audio control and intercommunication equipment, specified by British European Airways for the Comet and Vanguard fleets, providing crew intercommunication, selection and monitoring of the output of any three of 14 radio receivers, selection of any one of five radio transmitters, and limited facilities available during emergency conditions; a frequency-modulated sub-miniature radio altimeter, developed for the Ministry of Supply, operating in the 4,000 Mc/s frequency band, capable of measuring the altitude of an aircraft down to 2 ft; and a transistorised four-channel MF radio teleprinter developed for airborne use by Creed and Company Limited, and capable of operating at 100 words per minute.

MEASURING WEAPON VELOCITY

The radar division of Marconi's Wireless Telegraph Company Limited, Chelmsford, are showing EVA—a portable and quickly set up electronic velocity analyser for field use, capable of measuring accurately weapon velocity performance over the whole range of air-to-air, surface-to-air, and surface-to-surface missiles. EVA can also be used to measure the speeds of aircraft and road vehicles. The components are shown in Fig. 1, attached.

EVA operates in the X-band; the basic equipment covers the 2 to 80 m.p.h. range. By the addition of stable oscillators working (for example) up to the 50 kc/s region and an amplifier detector chassis, the equipment can then check speeds up to 3,000 ft per sec. Even higher speeds can be checked if required.

A typical version, with a 50 milliwatt output and 20° (horizontal) and 6° (vertical) beam widths, has a range of about 250 ft against a projectile target with an effective radar reflecting surface of $\frac{1}{3}$ sq. metre. A superheterodyne receiver has been incorporated to bring this range up to 1,000 ft. Other versions with greater transmitter powers give ranges which are commensurately greater (from three to nine miles can be achieved).

The speeds are recorded on moving Teledeltos paper and give a graphical representation against calibration pins every $\frac{1}{10}$ sec.

SOLAR-ACTIVATED CELLS

Solar-activated cells are demonstrated by Chloride Batteries Limited, Clifton Junction, Manchester. Activated by the rays of the sun, they are used to re-charge small orthodox batteries. Thus the variable output of the solar cell, which is dependent upon the intensity of the sunlight, may be converted to a steady usable supply by the orthodox accumulator. This is the combination used in space satellites, where radio transmitters have been kept working for very long periods—much longer in fact than would have been possible without taking advantage of solar energy. Also on view, on Chloride Batteries stand, are small unspillable very high output batteries for guided missile operation, and small water-activated batteries for operation in salt or fresh water.

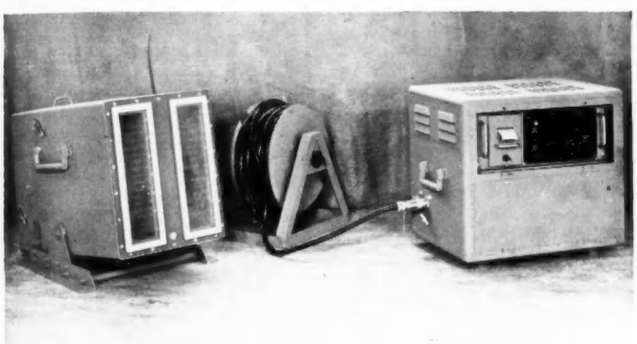


Fig. 1 (left) EVA, Marconi's electronic velocity analyser for measuring weapon velocity performance.

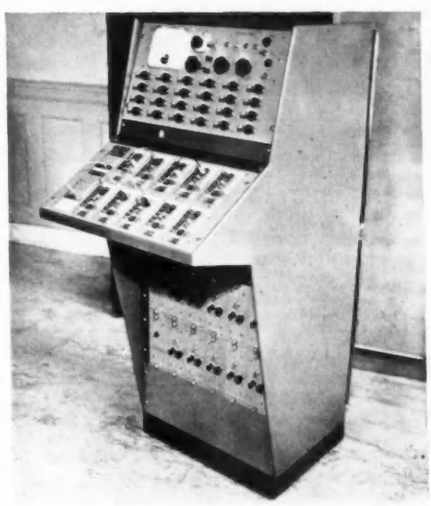


Fig. 2 (right) Solartron "Minispace" desk analogue computer.

MINIATURE ANALOGUE COMPUTER

A small inexpensive analogue computer, Minispace, for desk use in research, development and design departments, has been introduced by Solartron Electronic Group Limited, Thames Ditton, Surrey, described by the makers as an "electronic slide rule."

The Minispace is completely self-contained and comprises ten drift-corrected d.c. amplifiers with all the necessary input and feedback compoents, potentiometers, control and patching panels and power supplies. Non-linear elements are incorporated and expansion facilities are provided. The whole is contained in a cabinet 51 in high, 20 in wide and 30 in deep. The high stability power supplies, giving a total of 400 mA at ± 300 V, are mounted below desk level. Space is provided for the addition of the Solartron servo multiplier type TJ725.

Each of the ten amplifiers may be used for summing, sign reversing, integration or the simulation of a transfer function over a wide range. Thus, any problem requiring up to ten such operations may be solved or simulated, such as: two simultaneous second or third order differential equations; one equation of the fourth or fifth order; network analysis, resonant circuits with variable damping; critical damping; servo systems with multiple loops, damping terms, end stops, etc.; coupled mass-spring-friction systems; viscous damping, and so forth.

With the Solartron servo multiplier TJ725, the Minispace may be used as a multiplier, resolver, or non-linear function generator for many more complex problems.

Two Minispaces may be coupled together and operated from the control panel of one, thus making a 20-amplifier installation, or two ten-amplifier units with their own control panels, as required.

Among the navigation instruments seen at Farnborough is a polar path compass system, made under licence from the Bendix Aviation Corporation of America by Elliott Brothers (London) Limited, Lewisham, London. It is based on a recently developed high-precision directional gyro which is given servomechanism monitoring for heading indication and control. The directional gyro output, corrected by manual setting for drift error, is available for use in grid navigation and rhumb line flight. It also may be slaved to the output of a pendulous fluxgate compass transmitter on a course flown to a magnetic reference.

The system can thus provide two modes of operation: gyro direction sensing, with drift correction, when flying to a grid or other non-changing course; and directional gyro with heading information slaved to the output of the fluxgate compass when navigating to a magnetic reference. The slaved mode is utilised in areas where the earth's magnetic field is reliable (essentially mid-latitudes along standard air routes), and the directional gyro mode is used for other conditions or navigational techniques, such as grid navigation or when flying rhumb lines.

Another Elliott development is an autopilot system for installation in the latest types of high-speed fighter aircraft; it provides three-axis autostabilisation, a manoeuvre-holding facility, and an automatic instrument landing system coupler.

The autostabiliser system for each axis consists basically of a gyro which senses the angular rates associated with short-period oscillations and feeds correcting signals via an amplifier to small servos in the linkage between the pilot's control and the power servos. Signals given by steady rates may be blocked if required so that there is no opposition to steady turns or other manoeuvres involving steady rates.

Atomic Review

Geneva Sequence

ONE of the great film directors said that by placing a series of apparently unrelated images in sequence a new more vivid image might emerge. Looking through the papers being presented at the Second International Conference on the Peaceful Uses of Atomic Energy, one sees many references to beryllium, to high-temperature gas cooling, to uranium oxide, to plutonium recycling, and to heavy-water moderators. More diffident mention is made of fast reactors; and somewhere the Russians have no doubt revealed the workings of their superheated-steam reactor, a principle with which the British too have shown themselves familiar in discussion. A gas-cooled system with the benefits of condensation would certainly appear to be attractive. The excerpts from fission-reactor papers reprinted below, will be followed in a later issue with a similar montage of fusion items.

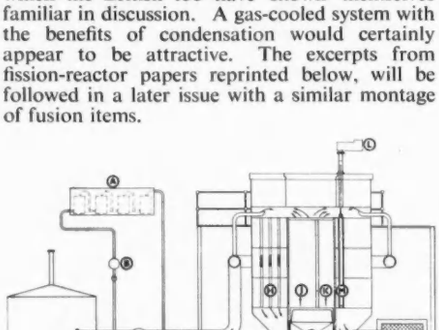


Fig. 1 Arrangement of the prototype high-temperature gas-cooled reactor which GEC are building for the UKAEA at Winfrith Heath.

A	Purification plant	E	Gas cooler	J	Core
B	Blower	F	Cool gas	K	A fuel element
C	Gas holder	G	Heater	L	Control gear
D	Gas circulating pump	H	Reflector	M	A control rod
				N	Gas filter

Fission Reactors

EDF1 and EDF2 (France)

Electricité de France and the Commissariat à l'Energie Atomique were concerned, in the designing of EDF1, to obtain as much information as possible to round out what was expected from reactors G2 and G3. This largely accounts for the presence of a metal envelope, the vertical placement of rods in the structure, and the electric equipment of the blowers.

A preliminary study had shown that the reactor could be accommodated in a cylindrical housing of 10 m in inside diameter. Adoption of this first datum served to determine the pressure at a value of 25 kg per sq. cm, the maximum compatible with available technical means for making the envelope at that time. . . .

The reduction in number of channels and the high specific power led to adoption of a hollow slug in which the hole, of small size, serves to reduce the temperature gradient in the uranium. However, nuclear considerations limited the relative diameter of the central hole and the cross sectional area of the uranium, the element finally chosen having an outside diameter of 3·5 cm and a 1·4 cm hole. . . .

Of high output (167 MW net electric) compared to the EDF 1 plant, the EDF 2 powerplant will have a reactor of the same type supplying two turbo-alternator groups. It is to go into operation 18 months after EDF 1. . . . Increased size and unit power make it possible to take full advantage of the capacity of the EDF 1 type reactor, and at the same time to build a plant of simple design and adequate characteristics.

The version adopted for the general characteristics of the reactor is on the whole similar to EDF 1: two-zone lattice, fuel elements of large section, same technological limitations (i.e. max. temp. in uranium is 550° C and max. temp. on magnesium jacket 400° C). However, it differs in certain important respects, and on the whole represents an improvement in point of performance. Analyses conducted in the course of construction of the EDF 1 vessel showed that it was possible to build a spherical vessel of the same thickness. This technical advance made it possible to provide, at the same pressure of 25 kg per sq. cm, for a reactor of much larger size accommodated in a sphere about 20 m in diameter. Calculation and preliminary layout showed that it was comparatively easy, in a space of this size, to accommodate a multiplier medium containing about 250 tons of uranium, and the optimisation was figured on the basis of these data. . . .

The shortening of channels was utilised both to increase the maximum specific power slightly and to add 20° C to the gas inlet temperature in order to permit possible improvements in transfer coefficient and life of jacketing material. The large size of the multiplier block permits considerable flattening, more than a third of the channels being in the concentrated zone. The neutron balance being more favourable than in EDF 1, the fuel elements are all alike. . . .

The protective sphere constructed for EDF 1 for experimental reasons has been eliminated in the EDF 2 project. (M. Boux and M. Bienvenu, *The Chinon Nuclear Power Plant*, P/1135 France.)

American Gas-Cooled Reactor

The United States have more recently taken serious interest in the gas-cooled system. A section through a plant proposed by the Oak Ridge National Laboratory, known as GCR-2, is shown in Fig. 2. An enriched gas-cooled reactor will produce cheaper power in the United States than a natural uranium gas-cooled reactor. This follows from the large reduction in capital costs achieved by enriching the fuel, combined with the fact that no serious penalty is paid in increased fuel costs as a result of fuel enrichment. It appears that at the present time gas-cooled reactors are economically competitive with the best available pressurised-water reactors in the United States. (R. A. Charpie *et al*, *Design Study for a Graphite-Moderated Gas-Cooled Reactor Using Partially Enriched Uranium*, P/450, USA.)

Promising United Kingdom Reactors

The gas-cooled reactor has proved capable of much further development. Extensive increases in output without undue penalty in capital cost have already been achieved by engineering improvements in the basic Calder Hall system.

Further substantial improvements, resulting in still higher temperatures and fuel ratings, should be possible if enriched fuel is used together with a canning material capable of withstanding the more severe operating conditions that will be experienced. To this end the UKAEA are examining the use of uranium oxide fuel and beryllium for canning. These might permit a gas outlet temperature of up to about 550° C, and, thanks to the greater stability under irradiation or ceramic fuels, a much increased burn-up which might ultimately be upwards of 6,000 MWD per ton. The UKAEA are now engaged on the design of an advanced gas-cooled reactor of this type and will shortly begin its construction. . . .

The Authority have more recently examined a further system which they believe should be capable of development for commercial operation in the later 1960's. This is also a gas-cooled system, but uses heavy water as the moderator. It should be capable of being built in large sizes, say 500 MW(E), but because of the cost of the heavy water the capital costs of this system would probably be higher than those of the sodium graphite system. They might also be a little above those of the gas-cooled system if all the economies expected from the latter can be achieved. On the other hand, the system is basically simpler; maintenance should be easier since no pressure vessel would be needed and the use of heavy water as a moderator avoids some of the problems, for example, of stored energy and oxidation, inherent in the use of graphite. If the study of the system now proceeding shows promise, the Authority would probably start fairly soon to design and build a reactor experiment or prototype . . . . .

Turning to the rather more distant future, the UKAEA hope that in the 1970's it will be possible to realise the advantages both of the fast reactor and of the high-temperature gas-cooled reactor which stands at the end of the gas/graphite route. The layout of the prototype HTGC reactor which the General Electric Company are building for the UKAEA at Winfrith Heath, is illustrated in Fig. 1. A high-temperature gas-cooled reactor system, using highly enriched ceramic fuel incorporated in a solid moderator and thus avoiding the use of metal fuel elements or sheaths, offers the possibility of sufficiently high temperatures that the reactor may ultimately be capable of being used in conjunction with a gas turbine. At these high temperatures thorium fuel elements enriched with uranium 233 should prove more economical than uranium 238 and plutonium. A conversion factor approaching unity should be possible on the Th 232–U 233 cycle. The fuel costs of this reactor should be low, thanks to the high rating and long life of the ceramic fuel elements; this

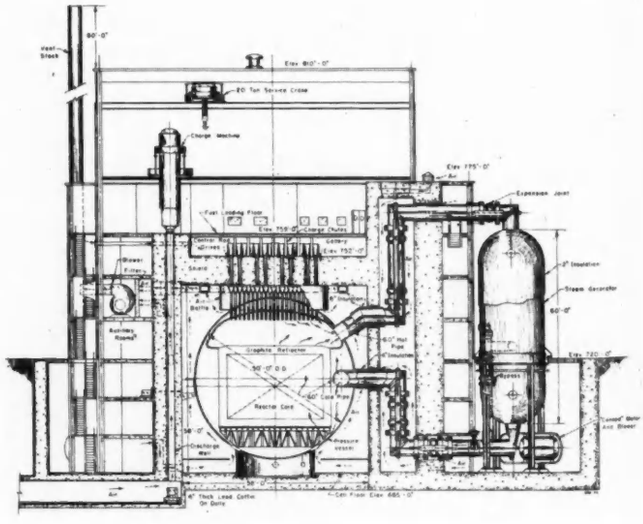


Fig. 2 Vertical section through reactor and reactor bay of the United States design study gas-cooled reactor GCR-2 (Oak Ridge National Laboratory).

factor together with its small size, and hence its low capital cost in relation to output, should result in overall generating costs substantially lower than those of its predecessors. However, many years of development work upon this system are still needed. (W. Strath, *The United Kingdom Programme for the Development of Nuclear Power*. F/P/262 UK).

Improved Fuels and the AGR

One use for plutonium is to re-cycle it in the reactors in which it is produced, so reducing the uranium 235 enrichment required for the replacement charges. In general, this reduction will depend on the fraction of the plutonium re-cycled, on the initial enrichment and on the nuclear characteristics of the reactor. In the limit, when all the plutonium produced by the reactor is re-cycled, it is found that for many designs the fuel enrichment required is lower than natural uranium, thus enabling some of the depleted uranium in the rejected fuel to be re-cycled as well.

For example, in a typical design using oxide fuel elements canned in beryllium, operating to 6,000 MWD per tonne burn-up, if all the plutonium is re-cycled, approximately 50 per cent of the rejected uranium can be re-used together with a make-up of 50 per cent natural uranium. This corresponds to a rate of heat extraction from the natural uranium of 12,000 MWD per tonne. Thus, this cycle not only allows a reactor initially requiring enriched uranium to operate on natural uranium feed material but it also achieves a higher effective burn-up of natural uranium than the once-through cycle.

A practical target for the development of metallic fuels may be about 4,500 to 6,000 MWD per tonne. Above this, say 6,000 to 10,000 MWD per tonne, the ceramic fuels appear more attractive, especially where new cladding materials allow higher surface temperatures than are possible with Magnox. The general advantages of ceramics are their high melting points, isotropic structure, absence of phase changes and their ability, under appropriate conditions, to withstand high irradiations without external dimensional changes, while at the same time retaining most of the fission-product gases within the lattice. In addition, uranium oxide (UO_2) has excellent compatibility with both carbon dioxide and cladding materials and since its production is simple and its sintering characteristics reasonably well known, it is most suitable for early development. . . .

The design of uranium oxide elements involves a neat compromise between rating, dimensions, can strength and burn-up. It is difficult to develop this compromise in the usual type of materials testing reactor, since it is almost impossible completely to match the thermal and neutron conditions, on which the results so closely depend, to those of an actual power reactor. Furthermore, it is known that the irradiation characteristics of different samples of sintered UO_2 may vary greatly. The excellence of fit between can and fuel is also important. Sufficient results have been obtained, however, to indicate clearly that with suitable material and design the high burn-ups are feasible. . . .

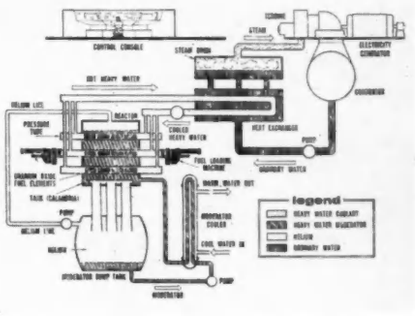


Fig. 3 Arrangement of NPD-2, the Canadian 20 MW(E) pressure-tube heavy-water cooled and moderated power reactor now under construction.

The United Kingdom Atomic Energy Authority is proceeding with the design and construction of an experimental advanced gas-cooled reactor (the AGR project). The plant will be completed early in 1961. The AGR is designed to operate at a high temperature and high fuel rating. The primary fuel is uranium oxide clad in beryllium and the flexibility of the plant is such that, while only the first charge has been specified, later charges either radically different or of more advanced design can be readily accommodated. Features of the AGR are given in Table I on this page.

TABLE I *Main Parameters, Performance and Design Data of the AGR*

General	
Reactor heat rate	100 MW
Net electrical output	28 MW (E) approx.
Reactor Core	
Core length (excluding reflector)	14 ft
Core diameter (excluding reflector)	15 ft
Total number of channels	250
Gas pressure at inlet to reactor	270 lb per sq. in
Gas temperature at inlet to reactor	250° C rising to 325° C
Bulk gas outlet temperature	500° C rising to 575° C
Normal maximum fuel element can surface temperature	600° C
Fuel Physics Data	
Total weight of UO_2 fuel in core	14·6 tonnes
Mean reactor rating	7·75 MW/tonnes U
Peak reactor rating	18·00 MW/tonnes U
Initial enrichment	1·65 C_0 (approx.)
Average thermal flux	$1{\cdot}49 \times 10^{13}$ n/cm² sec
Peak thermal flux	$3{\cdot}45 \times 10^{13}$ n/cm² sec
Control	
Number of control rods	25
Total reactivity absorbed	14 per cent (approx.)
Engineering Data	
Cylindrical pressure vessel, internal dia.	21 ft
Cylindrical pressure vessel, overall height	60 ft (approx.)
Weight of moderator, including reflectors	200 tons (approx.)
Number of external circuits	4
Number of main circulators	4
Power of circulator coupling	1,200 h.p. (approx.)
Charge and discharge of fuel	On load
Steam cycle	Single pressure
Superheater outlet pressure	620-670 lb per sq. in (g)
Superheater outlet temperature	860° F (460° C)
Turbo-alternator	One
Dump condenser rating	100 MW

(R. V. Moore, H. Kronberger and L. Grainger, *Advances in the Design of Gas-Cooled Graphite-Moderated Power Reactors*, P/312, UK.)

Canadian Heavy Water Power Reactor (NPD-2)

In mid-1955 design was started by the Canadian General Electric Company Limited, in partnership with Atomic Energy of Canada Limited and the Hydro Electric Power Commission of Ontario, of a 20 MW(E) power station. With the intention of producing a reactor with the least possible development and reliance on new materials, a pressure-vessel arrangement was selected, although it was realised that it did not lend itself to development for the largest sizes of power plants. This design, now called NPD-1, was carried out until early 1957 when, for a number of reasons, it was decided to investigate the use of a pressure-tube arrangement. By the end of 1957 it was apparent that the latter would serve the requirements of the Canadian reactor programme more effectively. It is this power plant, known as NPD-2, and shown in Fig. 3, that is now scheduled for completion in 1961. (I. N. MacKay, *The Canadian NPD-2 Nuclear Power Station*, P/209 Canada.)

American Heavy Water Power Reactor

Late in 1956 the United States Atomic Energy Commission expanded its development efforts by authorising a study of the feasibility of producing useful power from an atomic reactor that is fuelled with natural uranium and moderated with heavy water (D_2O). This task was assigned to E. I. du Pont de Nemours and Company largely because of the experience that it had gained from the design, construction, and

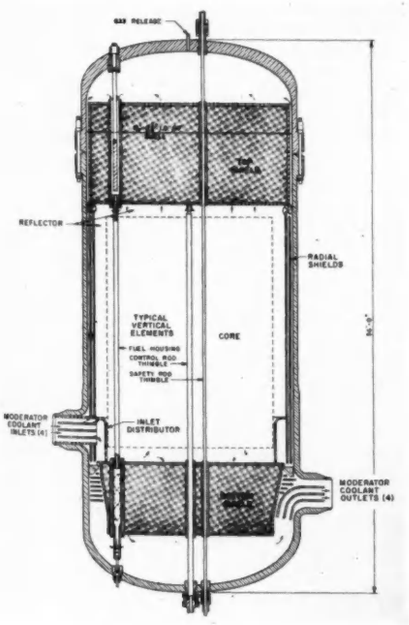
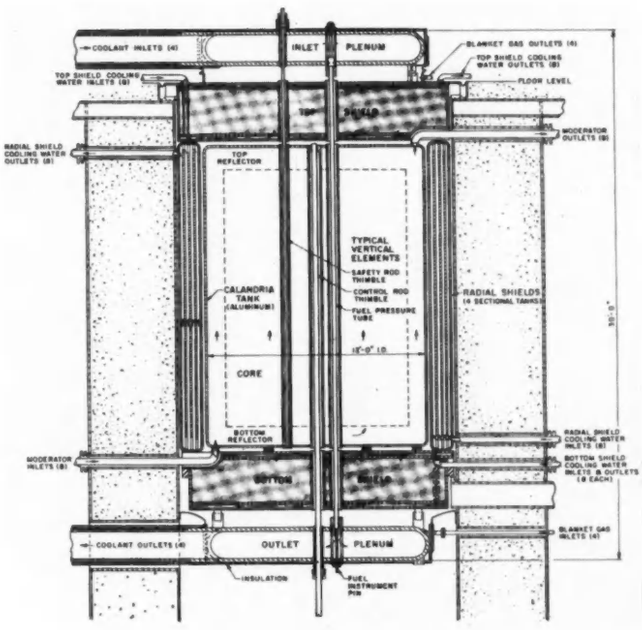


Fig. 4 (left) Pressure-vessel type of heavy-water cooled and moderated power reactor.

Fig. 5 (right) Pressure-tube type of heavy-water cooled and moderated reactor.



Continuing Atomic Review

operation of the Savannah River Plant. . . . . For present purposes it is assumed that the atomic reactor produces 450 MW of heat (100 MW electric) and is cooled and moderated with liquid heavy water. The inventory of heavy water in the reactor system is assumed to be 130 tons. Problems are avoiding losses of D_2O, and maintaining it at a sufficiently high level of isotopic purity. . . .

Four different reactor types were studied. Each would be fuelled with a tubular fuel element. A drawing showing the basic design of a pressure shell type reactor is given in Fig. 4; Fig. 5 gives a drawing of a pressure-tube reactor.

The chief advantage of pressure-tube reactor lies in the fact that it can be constructed in pieces that are of such a size that shipment to the construction site would not be a major problem. Also the construction of a significantly larger reactor would not require that new techniques be developed for fabrication such as might be required for larger pressure shells. The pressure-tube reactor has not looked good because of the shortcomings in the designs developed to date for the joining of the zirconium pressure tubes to the header system. A major amount of development and testing may be required before an acceptable pressure tube reactor could be constructed. On the other hand, it is believed that the techniques required for building of a pressure shell type of reactor are so near at hand that only a minor amount of development would be required before construction could start. (Dale F. Babcock. *Heavy Water Moderated and Cooled Power Reactors* P/610 USA)

Heavy-Water Boiling Reactor

In 1955, it was said that the Norwegian Institutt for Atomenergi (IFA) intended to concentrate its efforts in realising a boiling heavy-water reactor project. This project was started in 1956, by Institutt for Atomenergi as builder and main contractor.

TABLE II *Design Parameters for Halden Boiling Heavy Water Reactor*

Design pressure, primary side	40 kg per sq. cm
Design temperature, primary side	250° C
Design output	10,000 kW
Reactor vessel diameter	2·7 m
Lattice system, hexagonal c/c	130 mm
Available lattice points	325
Reactivity control:	
Cadmium tubes	19
Diameter on lattice points	50 mm
Cooling:	
One D_2O condenser for 10,000 kW in natural circulation	20 cub. m per hour
One D_2O cooler for 1,500 kW in forced circulation	80 cub. m per hour
Heavy water content, total	16 tons

(Nils Hidle and Odd Dahl, *The Halden Boiling Heavy Water Reactor*, P/559, Norway.)

Indirect Cycle Boiling Water Reactor

The plan of a 125 MW nuclear power plant was formulated with a view to its construction in Belgium in the near future. This was a joint project of the General Nuclear Engineering Corporation and BelgoNucléaire. After a critical analysis of the economic conditions and manufacturing possibilities of Belgium, on the one hand, and the advance of nuclear technology on the other, a boiling-water reactor was finally chosen. It was decided to adopt an indirect cycle with the primary loop completely separated from the secondary loop by heat exchangers. There is thus no problem of contamination of the superheater, turbine and the remainder of the secondary loop; their maintenance is thus especially easy. An indirect cycle also offers certain operating advantages because of the buffer formed by the exchangers. An oil-fired or coal-fired superheater completes the installation and permits a very high net efficiency (37·1 per cent) after auxiliaries are deducted.

The BelgoNucléaire plant calls for an indirect cycle. The steam and circulating water in the primary loop carry heat liberated in the core to heat exchangers which completely isolate this loop from the entirely conventional secondary loop. Water coming from the heaters evaporates through absorption of heat in the exchangers. The steam thus formed drives a turbine. (W. H. Zinn *et al*, *A 125-MW Indirect Cycle Boiling Water Power Reactor*, P/1801, Belgium.)

Dounreay Fast Reactor Delay

The fast reactor experiment project was undertaken with a rather long time scale because the development problems were known to be formidable and because the type of reactor involved was believed to represent an excellent long term prospect in fissile material utilisation.

This project was authorised in March, 1954, with a completion date early in 1958 in mind. It was known from the design study that the reactor core would contain a sufficient quantity of fissile material that under fault conditions it would be necessary to ensure against a criticality incident by suitable core design. In particular, with the fuel element ratings which must be achieved if an economic system were to be developed the rate of heat production from decay of fission products in the core was sufficient to cause melting of metallic fuel if the liquid-metal coolant were lost. It was hoped to overcome this problem by the use of a core made up of suspended elements suitably clad, so that elements which melted would separate and fall into a catchpot, reducing the reactivity of the assembly. Mechanical vibration problems ruled out this solution and a bottom tube plate was incorporated in the design. It was then necessary to ensure that if a core melt out occurred uranium would not accumulate on the tube plate as a critical assembly, and a solution to this problem was sought by the use of a tubular fuel element of which the inner and outer surfaces were canned in dissimilar metals so chosen that the inner can melted first. To obtain suitable materials a large investigation was undertaken and niobium and vanadium were selected for the outer and inner cans respectively. The development of the production technology for these materials was a project of some difficulty but by the end of 1956 it appeared that the manufacture of suitable fuel elements was practicable.

In mid-1957 when prototype production fuels were under test it was found that the safety device functioned but that the uranium-vanadium mixture resolidified under experimental conditions before leaving the central tube. It was impossible to simulate in these tests the exact temperature distribution expected in the reactor, but since in the experiments the resulting plug did not remelt before the outer can failed, a doubt remained. Modifications to the fuel-element design were thus required to be made when the fuel element production line was already constructed. In fact, a shortage of technical staff has made it impossible to satisfy all the requirements of our programme and it has become necessary to delay the criticality date of the reactor. The reactor core has been modified to reduce the probability of refreezing of the molten uranium and to ensure that the flow path of the molten material is such as to avoid a criticality incident. (Sir Leonard Owen, *Some Experiences in the Industrial Group of the UK Atomic Energy Authority*, P/301, UK.)

Design Problems of Dounreay Fast Reactor

At an early stage of design it was decided to have coolant flow down through the core. With a philosophy of safety based on the idea of the fuel breaking away downwards and dropping clear of the reflector in the event of overheating it was the original intention to support the fuel elements from the top and have no bottom plate. To permit loading and unloading, the fuel elements would have to pass through the holes in the support plate at the top and therefore they would have been separated from one another below the plate by fairly large clearances. It was feared that under these circumstances the fuel elements would be subject to flutter and vibration due to the hydrostatic forces, and experiments were made on a model to check this. These experiments confirmed that this was likely to happen and the idea of top support had therefore to be abandoned. Because of the problems of ensuring adequate cooling of the fuel elements, no satisfactory design of support plate could be produced for other than either the top or the bottom, and so a bottom support plate was finally adopted. The outer can of each fuel element was also ribbed to prevent the walls of adjacent fuel element cans touching and so causing hot spots on the elements. A system of spiral ribs in bands was adopted as this ensured that ribs of adjacent elements would touch irrespective of the orientation of the fuel elements.

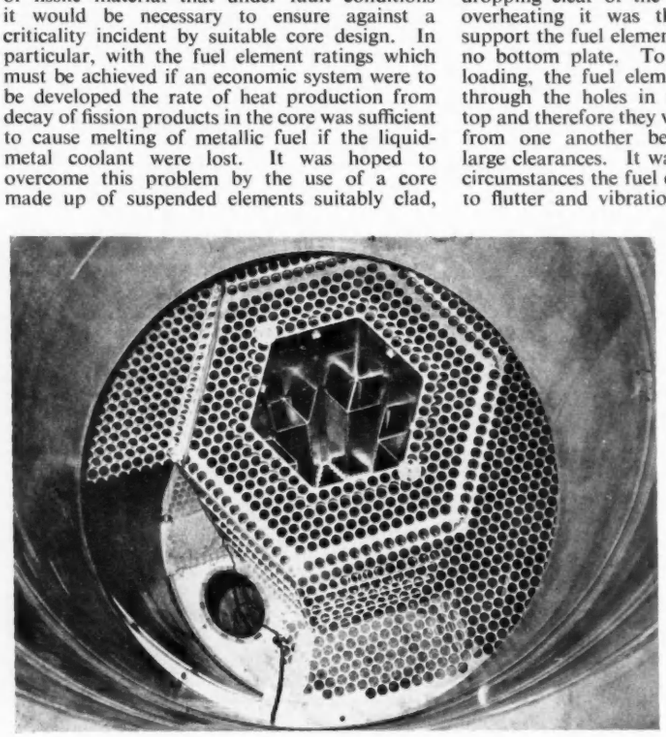


Fig. 6 View looking into the Dounreay fast reactor from the top of the eccentric shields, showing inner and outer breeder support structure and core space.

During 1957 a considerable amount of theoretical work was done on the stability of fast reactors following the melt-out of the EBR-1 core and it became clear that with the proposed design of core assembly for Dounreay, at quite modest power ratings the radial temperature gradients in the core were sufficient to cause the fuel elements to bow towards the centre. Above the bottom plate the fuel elements were located by each other; this meant that the amount of bowing could be the total accumulation of all the clearances across the core and was appreciable. It was recognised that such an effect would lead to a prompt positive contribution to the power coefficient and would cause instability in the reactor. . . .

The problem was eventually overcome by designing a form of tube nest which gave lateral restraint at the centre but did not unduly restrict the cooling. Some adjustment had to be made to the fuel element pitching and this was changed from 0·83 in to an average of 0·91 in and the total number of fuel elements reduced. The provision of this support meant that each fuel element could not move by an amount more than its own clearance within the tube nest and the cumulative effect which had made the bowing problem serious was eliminated. Fig. 6 is a view looking from the top of the eccentric shields of the Dounreay fast reactor, showing inner and outer breeder support structure and core space. (H. Cartwright, J. Tatlock and R. R. Matthews, *The Dounreay Fast Reactor—Basic Problems in Design*, P/274.)

Notes and News

Britain Exports 200 MW Station

A contract has been signed between the Nuclear Power Plant Company Limited, Knutsford, Cheshire, and the Italian organisation, SIMEA, for the construction of a 200 MW nuclear power station. It is to be sited at Latina, 40 miles south of Rome. Work has already started, both in Britain and Italy, and the station is scheduled to be in full commission by the middle of 1962.

The contract is worth over £10 million to British industry and is the outcome of an agreement signed between the Nuclear Power Plant Company and AGIP Nucleare, Milan, in May last. This agreement provided for collaboration in the construction of nuclear power stations in Italy over a minimum period of 7 years. The Società Italiana Meridionale per l'Energia Atomica (SIMEA)—a company 75 per cent controlled by AGIP Nucleare—began work on the site this summer, and it is expected that the total cost of the station will exceed £20 million. Equipment supplied by Britain includes the complete reactor, the turbo-alternators, and the blower apparatus. The United Kingdom Atomic Energy Authority will guarantee the fuel supply for the life of the station. Italy plans to construct enough nuclear power stations to provide 2,000 MW by 1967—the equivalent of ten stations like that at Latina.

Cheaper Heavy Water

Constructors John Brown Limited have devised and perfected a new system of heavy-water production from hydrogen. It can be operated economically on a relatively small scale, for example, as an ancillary to the production of synthetic ammonia. The CJB system is based on a combination of ammonia exchange and ammonia distillation. Being a byproduct the heavy water is produced at a comparatively low cost. It is said that in one instance the direct operating costs, leaving aside capital charges, would be less than one-third of the price announced by the USAEC for the sale of their product to approved purchasers.

The ammonia hydrogen exchange process can extract the deuterium from any mixture of hydrogen provided that the gas is dry and free from acidic constituents. Where the ammonia synthesis gas has already been washed with liquid nitrogen there are no purification problems and no condensation of solid materials can block equipment and cause shut-downs. The CJB heavy water plant uses only standard equipment and components of proved reliability.

The CJB process can simultaneously produce ammonia enriched threefold in nitrogen 15 which would reduce its cost proportionately. There will be an increasing demand for this isotope and its sale would further reduce the production cost of heavy water.

US Heavy-Water Prices

The amount of heavy water contained in natural water varies slightly, depending on the source of the water, but averages one part in 6,500 or approximately 0·015 per cent of deuterium oxide. Heavy water (D_2O) is obtained by concentrating this very small proportion to any desired degree of purity. Several methods of doing this have been used commercially—namely, dual-temperature chemical exchange, water distillation, electrolysis of water, and combined electrolysis of water and steam-hydrogen chemical exchange. Heavy water is packaged in stainless-steel, non-returnable, non-refillable drums. The drums are of two sizes, containing net weights of 125 or 500 lb of D_2O and costing about 43 dol and 100 dol respectively. The cost of the containers is added to the D_2O charge of 28 dol per lb for shipment.

Calder Turbine Accident Report

The report has now been completed of a board of inquiry set up by the United Kingdom Atomic Energy Authority to inquire into the circumstances of an accident which caused damage to a turbo-generator in the "B" power house at Calder Hall Nuclear Power Station on 28 June, 1958. The machine which failed was the fifth to be installed; acceptance tests were being carried out but the Authority had not formally accepted delivery. From the evidence given to them the board concluded that the overspeeding and ultimate disintegration of the turbo-alternator was caused by the coincident failure of two valves to function automatically. Examination of these valves showed that part of them had been scratched and scored by solid particles which were subsequently identified as fragments of chilled iron shot which had found their way into the steam system. The report continues "While the board recognised that they had been unable to establish fully how shot came to be in the steam system under the strict conditions which had been set down to prevent it they felt bound to recommend that in order to avoid future accidents of a similar nature additional precautions should be taken to ensure that hard materials where these were known to be used did not enter or remain in the system." Although the accident involved no release of radioactivity, the board also considered possible secondary consequences which might have arisen. It reached the conclusion that the reactor had not been put in any danger.

Reactor Runs on Plutonium

A reactor at the USAEC's National Reactor Testing Station near Arco, Idaho, is reported to have operated on plutonium fuel. The plutonium may have been in the form of enrichment in uranium.

British Atomic Energy Work Shown in Sweden

The Board of Trade is staging a small display about Britain's atomic power industry at the St. Erik's Fair, Stockholm, from 30 August to 14 September. Covering 1,000 sq. ft, the British exhibit includes a model of Calder Hall power station and photographs, diagrams and text illustrating British progress in the development of atomic power for peaceful uses. It is on loan from the United Kingdom Atomic Energy Authority.

Thermonuclear Research Declassification

The United Kingdom and the United States have declassified their programmes of research on the control of thermonuclear reactions. Sir John Cockcroft and Mr. Lewis L. Strauss announced this last week in Geneva. There has been complete exchange of information in this field between the United States and the United Kingdom since 1956 and the two countries have been operating under a joint classification guide. The declassification action will make possible a freer flow of information between the United States and the United Kingdom and also other nations. When administrative arrangements can be completed this decision will make it possible in addition for scientists and engineers from other countries to pursue studies at certain research centres where work on controlled thermonuclear energy is in progress.

Anglo-American Group Sells Power Reactor

Negotiations for a 22 MW boiling water power reactor plant have been completed between the Anglo-American group—Mitchell Engineering Limited and the American Machine and Foundry Company—and Cuba.

Locating Geneva Exhibitors

Apparatus employed in nuclear research is described in an article on page 324, the third in a series of four describing equipment now being shown at the Atoms for Peace Exhibition in Geneva. A list of the firms mentioned in the third and fourth articles, together with their addresses and stand numbers, appears below.

The APV Company Limited, Wandsworth Park, London, S.W.18. (Stand No. 144.)
APV—Paramount Ltd., Manor Royal, Crawley, Sussex. (Stand No. 144.)
Avo Limited, Avocet House, 92-96 Vauxhall Bridge Road, Southall, Middlesex. (Stand No. 104.)
Cambridge Instrument Co. Ltd., Rugby, Warwickshire. (Stand No. 115.)
Cawkell Research and Electronics Ltd., Scotts Road, Southall, Middlesex. (Stand No. 122.)
Chance Pilkington Optical Works, Pilkington Brothers Ltd., Glascoed Road, St. Asaph, Flintshire. (Stand No. 144.)
Chesterfield Tube Co. Ltd., Chesterfield. (Stand No. 142.)
Constructors John Brown Ltd., CJB House, Eastbourne Terrace, Paddington, W.2. (Stand No. 141.)
Cossor Instruments Ltd., Highbury Grove, London, N.5. (Stand No. 117.)
Crane Packing Ltd., Slough, Bucks. (Stand No. 142.)
Dawe Instruments Ltd., 99-101 Uxbridge Road, Ealing, London, W.5. (Stand No. 117.)
Ekco Electronics Ltd., Ekco Works, Southend-on-Sea. (Stand No. 116.)
Electronic Instruments Ltd., Lower Mortlake Road, Richmond, Surrey. (Stand No. 117.)
Elliott Bros. (London) Ltd., Century Works, Lewisham, London, S.E.13. (Stand No. 113.)
EMI Electronics Ltd., Blythe Road, Hayes, Middlesex. (Stand No. 105.)
The Fairey Aviation Co. Ltd., Hayes, Middlesex. (Stand No. 101.)
Fleming Radio (Developments) Ltd., Caxton Way, Stevenage, Herts. (Stand No. 120.)
General Electric Co. Ltd., Magnet House, Kingsway, London, W.C.2. (Stand No. 124.)
General Radiological Ltd., 15 Clipstone Street, London, W.1. (Stand No. 108.)
High Voltage Engineering Corp., Burlington, Mass.
Hispano Suiza Société Anonyme, Rue du Capitaine Guynemer, Bois-Colombes, Seine. (Stand No. 134.)
H. M. Hobson Ltd., Fordhouses, Wolverhampton. (Stand No. 130.)
Humphreys and Glasgow Ltd., Humglas House, Carlisle Place, London, S.W.1. (Stand No. 46.)
Imperial Chemical Industries Ltd., P.O. Box 216, Kynoch Works, Witton, Birmingham. (Stand No. 140 and 122.)
Isotope Developments Ltd., Aldermaston Wharf, Nr. Reading, Berkshire. (Stand No. 103.)
George Kent Ltd., Biscot Road, Luton, Bedfordshire. (Stand No. 135.)
Labgear Ltd., Willow Place, Cambridge. (Stand No. 112.)
Marston Excelsior Ltd., Fordhouses, Wolverhampton. (Stand No. 140.)
Metropolitan-Vickers Electrical Co. Ltd., Trafford Park, Manchester 17. (Stand No. 103.)
Mond Nickel Co. Ltd., Thames House, Millbank, London, S.W.1. (Stand No. 138.)
Mullard Equipment Ltd., Mullard House, Torrington Place, London, W.C.1. (Stand No. 111.)
Nash and Thompson Ltd., Oakcroft Road, Chessington, Surrey. (Stand No. 117.)
Nuclear Graphite Ltd., 52 Battersea Church Road, London, S.W.11. (Stand No. 103.)
Plessey Ltd., Weedon Road, Northampton. (Stand No. 106.)
Pye Ltd., Atomics Division, St. Andrew's Road, Cambridge. (Stand No. 112.)
W. G. Pye and Co. Ltd., Granta Works, Cambridge. (Stand No. 112.)
Rio Tinto Group, Barrington House, Love Lane, London, E.C.2. (Stand No. 133.)
Shell Petroleum Co. Ltd., St. Helen's Court, Great St. Helen's, London, E.C.3. (Stand No. 139.)
Solartron Electronic Group Ltd., Solartron Works, Thames Ditton, Surrey. (Stand No. 110.)
Stanton Instruments Ltd., 119 Oxford Street, London, W.1. (Stand No. 117.)
Sunvic Controls Ltd., 10 Essex Street, Strand, London, W.C.2. (Stand No. 103.)
Talbot Stead Tube Co. Ltd., Green Lane, Walsall. (Stand No. 142.)
TI Nuclear Engineering Ltd., The Adelphi, London, W.C.2. (Stand No. 142.)
Townson and Mercer Ltd., Croydon, Surrey. (Stand No. 117.)
20th Century Electronics Ltd., King Henry's Drive, New Addington, Croydon, Surrey. (Stand No. 119.)
Tubes Ltd., Rocky Lane, Aston, Birmingham 6. (Stand No. 142.)
Unicam Instruments Ltd., Arbury Works, Cambridge. (Stand No. 112.)
Union Carbide Corporation, 30 East 42nd Street, New York 17, N.Y. (Stand No. 53.)
Vokes Ltd., Henley Park, Guildford, Surrey. (Stand No. 136.)

The Human Element

Labour Hoarding

The hoarding of labour by employers—" who had changed from regarding labour as a commodity always in elastic supply to treating it as something which, if once released, might not be easily replaced "—has been a major contributory factor to the low level of unemployment since the war. This view was advanced by Professor A. J. Brown, Professor of Economics at Leeds University, in an address to the economics section of the British Association last week.

Professor Brown discussed the post-war phenomenon of what he called an " astonishing " absence of unemployment. In the past years the average rate had been less than half the target level of 3 per cent deemed necessary by Lord Beveridge for a reasonable degree of elasticity in the economy. Nonetheless " the occupational and industrial structure of the economy has apparently been about as flexible under full employment as it was with a great deal of unemployment," chiefly because price movements affected demand in such a way as to produce changes in the industrial pattern.

To the firm which began its life during this period it is quite evident that there was very little flexibility indeed. Skilled workers or technically qualified men could hardly be obtained, or only at inflated salaries. Large firms tended to recruit many more than they required, particularly from the universities, and to hang on to them in case they were needed. The shortage of labour, and the hoarding which contributed to it, made the founding of enterprise to exploit radically new products or new techniques exceedingly difficult. To this were added the severe restrictions on the supply of finance imposed by successive governments in their efforts to halve inflation and the almost general hoarding of money by those companies who were earning well from established products. This period is now coming to an end, due to industry's inability to sell all it can produce. It is the time when hoarding—of labour or capital—becomes unnecessary. Already the effects are visible, particularly on the supply of engineers and scientists and, for a time the pendulum is likely to swing quite a long way back—much further than it would have done had it not been for the hoarding Professor Brown complains of.

Semi-Craftsmen

Training inadequacies on the craft side of industry were described as " potentially ruinous " by Sir Willis Jackson, director of research and education, Metropolitan-Vickers Electrical Company, in his presidential address to the Education Section of the British Association. " We have been proud to claim that British workmanship is the best in the world," he said, " and indeed there has been much truth in this claim. We shall be wise to recognise, however, that the justification for the claim is wearing precariously thin."

Sir Willis explained that this high standard had been achieved because firms were able to recruit straight from school, boys of high natural ability. The expansion of facilities for higher education means that a very large proportion of these boys now go on, either to higher level standard at school or to technical colleges, and in many cases to universities. " We must, therefore, expect a lowering in the quality of the entrants to craft apprenticeship at a time when what is wanted is a raising, not a lowering, of the standard of craft skill."

The only possible remedy is the provision of ample and good training facilities, and these, Sir Willis said, are not there. The supply of well-qualified and well-trained teachers is inadequate. The small and medium firms, in particular, suffered from a shortage of good quality craftsmen and technicians. Unless they can get them, and time is not on their side, " they are unlikely to be able to withstand the pressures of some other industrial countries, particularly in in the event of the establishment of a European Free Trade Area."

Stout is not Enough

A new type of public house and community centre will be erected at Hatfield New Town, at the initiative of Arthur Guinness Son and Company (Park Royal). The Hatfield Development Corporation are fully behind the scheme, which has been approved by the Ministry of Housing and Local Government and the Hatfield Licensing Justices.

The new centre, called Hilltop, will combine a public house and a community centre. It includes an assembly hall—which can be used as a theatre—a health clinic, three committee rooms and a cafeteria. Provision is made for the serving of food and for catering. There will be four bars, which can be separated completely from the rest of the building, and an off-licence.

As the policy of the Guinness company is not to own nor to operate public houses, the building will be erected and managed by McMullen and Sons, the Hertfordshire brewery, but half the capital will be advanced by Guinness on advantageous terms. They will have no tie on the licensed premises. Guinness will be two hundred years old in 1959.

The Scientific Reproach

There is room in industry for the scientist as a manager. In fact there is an urgent need for scientifically trained people in the administration of business. This was the view put forward by Sir Alexander Fleck, chairman of Imperial Chemical Industries, in his presidential address to the British Association last week (ENGRG., 29 Aug., p. 257). He argued that the employment of technical men in commercial departments gave flexibility within the business and that it often led to smoother co-operation with other departments " when a works manager or research chemist feels that his own, the technical point of view, is understood by a man in one of the commercial departments." Commercial experience, he added, is invaluable to the technical man as training for higher management.

Sir Alexander left his audience in no doubt concerning his view on the suitability of the scientist for the functions of higher management: " science has more to offer than mere tools. It offers the whole philosophy of the scientific approach to the problems of management." The gulf which at present separates scientists and non-scientists was much more easily bridged than is often imagined. For example, the qualities of mind which were fostered by studying chemistry and history were very much alike. Both chemists and historians must cultivate an inquisitive and acquisitive mind. Both needed to exercise judgment, leavened with a good measure of scepticism. Both must be imaginative, the chemist in advancing hypotheses to predict the future, the historian doing so to explain the past.

Deep-Freeze Immortality

The probability that some day soon science will give us the means of achieving suspended animation of a warm blooded animal at a temperature likely to result in a stable state was the subject of lively papers to the British Association meeting by Dr. A. S. Parkes and others. The research now being made into the biological effects of low temperatures has already yielded surprising results. In the words of Dr. Parkes, " at zero degree centigrade, the artificially cooled mammal has every appearance of being dead and by all clinical evidence it is dead. Yet, under appropriate conditions it can be revived. This situation poses the intriguing question of how to define death." As knowledge increases, forecast Dr. Parkes, the means of resuscitation will extend so that " what constitutes death today will not necessarily constitute death tomorrow."

Could this mean that Scott of the Antarctic and countless others did not die but were preserved indefinitely " in a state of animation suspended by cold? " Dr. Parkes leaves us in doubt as to this being a distinct possibility. The other papers support this general thesis by examples of what has been achieved and by describing work now going on. When it is realised that bull's sperm frozen in 1952 is still 66 per cent successful by recent artificial insemination, a new window of knowledge is thrown wide open.

Foremanship

A one-week training course for foremen and forewomen under the title of " Developing Foremanship Skills in Handling People " has been designed by the Industrial Welfare Society in an attempt to bridge the wide gap which appears to exist between theory—what foremen learn on the normal course or conference—and practice. Most of those who go to find out how they should do their job find that when they are back at work—where mistakes cost money and lower personal prestige—conditions rarely permit them to experiment.

The new course is intended primarily for those who have already attended some other course on human relations. Formal lectures will be kept to a minimum. Delegates will work through leading and reporting discussions, undertaking group studies of general industrial matters, acting out various problems and interview situations and tape recording and analysing their verbal reports. The course will cover discipline, understanding resistance to delegation of responsibility, and controlling a group discussion.

TUC Oppose Nationalisation

On the final session of their examination of their agenda for this week's Congress, the General Council of the TUC decided to oppose two resolutions demanding the public ownership of the docks, shipping and the tobacco industry when they come up for debate. They will also ask the sponsors to withdraw a resolution calling for the nationalisation of the building industry.

They are fiercely opposed to the extension of their existing commitments, which of course include re-nationalisation of iron and steel and road transport. Moreover, discussions are already underway between the TUC and the Confederation of Shipbuilding and Engineering Unions on the public ownership of these industries.

Considerable criticism of the Government's economic policy has been incorporated in a variety of resolutions, most of which will be put to the Congress as " composites." Three resolutions deal with the Cohen Council's recent report, three are on wages policy and five criticise the Government's policy in general terms. This criticism is expected to be outspoken and to be vociferously supported by the vast body of delegates present. Maybe a note of realism will creep in towards the end.

Marketing

FAILURE OF A CHALLENGE

The Dunlop Rubber Company were granted an injunction recently to restrain a Bournemouth concern, the Longlife Battery Depot, from selling the company's car tyres at cut prices. Mr. Justice Lloyd-Jacob, the Chancery Division judge who gave judgment, held that distributors were not complying with Dunlop's re-sale conditions to which Longlife Battery were bound by a written agreement. He also found that there had been an infringement of letters patent which protected Dunlop's car tyres. Regarding the Restrictive Trade Practices Act, Section 25, His Lordship said it gave the supplier the right, so far as re-sale price conditions were concerned, to enforce the terms of his contract with the immediate purchaser against the sub-purchaser who was aware of the conditions at the time he acquired the goods. He found, however, that this section of the Act was not applicable to goods which were disposed of by the supplier before the Act came into force.

This judgment is of great importance to engineering firms selling their products through a distributor-agent network. Longlife Battery Depot acted " under a full panoply of defiance." The proprietor, Mr. John C. Clark, flew the skull and crossbones pirate flag over his premises as a symbol of his opposition to price maintenance by motor accessory manufacturers. This test case may not be the last, for there remains room for different interpretations of the Restrictive Practices Act. Nonetheless, it will reassure manufacturers that some kind of order will continue to prevail in re-sales and that their price policy and patents can find protection in the Courts.

Dunlop continue their expansion overseas. They have recently entered into an agreement with Federal Turk Kamyonlari A.S. of Ankara for the establishment of a tyre factory in Turkey. The project has the approval and support of the Turkish Government and is the outcome of negotiations which were finished recently in London between Dunlop and a Turkish delegation. Dunlop Advisory Service Limited will design the factory, which will satisfy the major portion of Turkey's tyre requirements, and Dunlop will acquire a financial interest in the project. Increasingly, this trend towards manufacturing overseas is gaining momentum in the vehicle component field. It must do so in all industries where the labour content of the product is relatively low in skill.

Thousands Cross the Atlantic

The performance of British car manufacturers in the United States continues to shine. In the first five months of the year, British firms shipped 62,833 vehicles valued at 76·7 million dol. During May, Britain remained the largest supplier of imported cars, despite considerable progress by other European manufacturers. Imports during the month totalled 11,596 cars from Britain, 10,111 from Germany, 7,916 from France, 2,238 from Italy and 2,045 from Sweden. The German figure was the only one which was lower than in April. But the total United States imports of German vehicles during the first five months of the year totalled 54,225.

The value of the United States market to European manufacturers is strikingly illustrated by the performance of the British Motor Corporation and the Renault company. During the financial year ended 31 July, BMC earned 75 million dol from American sources. A large percentage of the vehicles dispatched to the United States were Austin-Healey and MGA sports cars, 94 per cent of the production of which was sold abroad. The United States was the BMC's largest export market. Renault had sold more than 40,000 cars by the end of July and the company's target of 60,000 cars for the year will almost certainly be exceeded. Most of these are Dauphines, made even more popular by their spectacular victory in this year's Monte Carlo rally. Renault hope, nevertheless, to expand the sales of the 4 CV, which already represents 10 per cent of their total sales to the United States. A feature of European exports to America is that the British share consists chiefly of sports cars, while the German and French share is mainly saloon cars.

Higher Status for ECGD

The Export Credits Guarantee Department will still function as a Government department but may do so higher up in the hierarchy and with an increased establishment of senior officers. The Government decided to maintain the official status of the organisation " because of its use of public funds, its relation to the broader aspects of economic policy and its dependence on information from Government sources." The decision followed the submission of the report of a committee under the chairmanship of Sir Eric Speed who were asked a year ago " to consider the suitability of the present organisation and the future status of ECGD."

The emphasis during the next few years is likely to be on more and longer-term credit for export. Economic competition between nations struggling for political ascendency in the major undeveloped countries of the world makes this inevitable. The Speed Committee found that the highly developed and comprehensive facilities enjoyed by British exporters " had been administered wisely and with competence." There is to be a secretary of ECGD and the post, equivalent to the Civil Service rank of deputy secretary, is to be filled by Mr. L. J. Menzies, an adviser to the Bank of England who has been seconded by the Bank. Two under-secretaries have been appointed (at salaries of £3,400 per annum each) and the main recommendations of the Committee have thus been implemented.

Search for Good Distributors

The growing emphasis in selling—even the best products are having to be " sold " more and more energetically—is leading some firms in the engineering industry to the appointment of specialised sales firms as distributors of their products. For reasons similar to those which have led firms to purchase established companies, in order to diversify their products, or to aid the acquisition of manufacturing licences, manufacturers who are faced with the task of building up a sales and service organisation find it quicker, and easier, to conclude agreements with established distributing organisations. It is a way of buying time and can become a satisfactory long-term arrangement.

An example of this is the appointment by Chaseside Engineering Company Limited, Hertford, of William C. Search Limited of Leeds as sales and service distributors for Yorkshire last year, and the recent appointment of Search (Liverpool) Limited for Lancashire, Cheshire and North Wales. Sub-agents have been or are being appointed by them to provide spares and service facilities within approximately 50 miles, thus reducing repair costs and down time. This is a method used by many of the makers of contractors' plant and equipment, where prompt attention to service calls is so important, and one which is being used by some leading U.S. firms.

Petrobras and Brefcon

At the invitation of the Brazilian Government oil monopoly, Petrobras, representatives of a British consortium of oil equipment manufacturers recently visited Brazil to negotiate for the supply of equipment for a new refinery to be constructed near Rio de Janeiro. Foster Wheeler's are retained by Petrobras for the design, engineering and supervision of the refinery. The consortium, which was formed through the aegis of the Council of British Manufacturers of Petroleum Equipment, is the British Refinery Constructors, and is known as Brefcon. It includes the principal United Kingdom manufacturers of oil refinery equipment and allied products.

Brefcon is headed by Babcock and Wilcox Limited, the British Thomson-Houston Export Company Limited, Stewarts and Lloyds Limited, and John Thompson Limited; Balfour, Beatty and Company Limited are acting in a secretarial and co-ordinating capacity. As a result of the negotiations in Brazil, the Brefcon representatives received from Petrobras a contractural letter of their intention to purchase a minimum of four million pounds worth of equipment for the new oil refinery from Brefcon. This outcome was achieved in the face of French, German and Italian competition.

British Timken Entertain

The fourteenth British Timken Show was held at Duston last Friday and Saturday. Begun after the war as a small peace celebration, it has now become one of the leading shows of its type in Britain. BBC television cameras have helped to make it a national occasion. The tit-bit of this year's show was the British Show Jumping Association's Olympia trial, when the best show riders in the country competed for a place in the national team. Other horse jumping events were included, for men, women and child riders.

There were the usual livestock section and the horticultural show. The number of entries, 500 for the cattle section and 262 for the horticultural section, is evidence of the growing attraction of the show. A bird show, a demonstration of the use made of Alsatian dogs by the Royal Air Force police, a display of veteran cars and a mobile exhibition of the Thunderbird rocket unit completed each day's programme, as good as any in the country.

Last year over 30,000 people attended. There can be few concerns in this country that receive such attention. Perhaps all this bears little relation to the sale of bearings which the company manufacture. Yet, as a means of getting the company's name nationally known, the show must be an effective adjunct to prestige advertising.

Prices Rise Again

There is a widespread expectation that prices of commodities and costs generally will soon resume their upward climb. Both Wall Street and the London Stock Exchange reflect in raising their values the anticipation of renewed inflation.

In the United States, several price increases have followed those made recently by the steel industry. One Pittsburg company, A. M. Byers, have announced increases of 3 per cent in the price of their wrought iron products. The company are the world's largest makers of wrought iron products and also produce electric-furnace carbon, alloy and stainless steels and market p.v.c. pipe and sheet. Even more important than the actual increase is the implied warning of further increases by their vice-president sales, Mr. A. S. Chalfant: " Despite the higher manufacturing costs required for the production of wrought iron, we are holding our price increase down to the levels established by the basic steel industry and will absorb part of the additional manufacturing costs created by the USW wage increase granted on 1 July."

Buyers the world over traditionally (and wisely from their companies' point of view) buy mainly on a rising market. Psychologically the climate of business is becoming favourable to renewed expansion, and inflation.

Research and Development

NUCLEAR PROPULSION*

Prospects for Ships, Aircraft, and on Land

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When considering the application of nuclear power to propulsion purposes, two main questions have to be answered: Is it feasible and is it worth doing? Generally the answer to the first is yes—provided one is prepared to pay for it. The answer to the second depends upon the approach. Militarily, for instance, it may give considerable operational advantages, which are particularly noted in the submarine application in which it confers high underwater speeds for long periods without the need of oxygen for combustion, and hence a high degree of invulnerability. This is worth paying a substantial price for. Strategically, the wide application of nuclear power would lessen one's dependence on the overseas oil supplies. It has to be noted, however, that if applied to all new tanker construction for the United Kingdom until 1965 it might save 1½ million tons of oil per year. By that date the United Kingdom will probably have to import the equivalent of some 40 million tons per year to provide for other power requirements such as electricity generation, road and air transport.

A third approach to the question is the commercial one: will its use enable one to do a specific job as cheaply as, or cheaper than, doing the same job with conventional machinery? It is certainly not yet obvious that nuclear propulsion will permit any commercially attractive operation to be carried out which cannot be performed by conventional means, unless one looks much further than ten years ahead and envisages a need for supersonic long-range aircraft, very high-speed submarine tankers, or possibly space flight. These questions and an examination of how the facts of nuclear propulsion affect the answers form the basis of the paper. Comparisons are made with conventional plants as appropriate to provide the necessary background.

BASIC FEATURES

Mobile propulsion plants demand small specific weights (lb per s.h.p.), small specific volumes (ft^3 per s.h.p.), small capital and running costs, low maintenance, and, since risks inevitably accompany mobility, high reliability. The consequences of failure of the power plant differ for the various applications but usually they are dangerous or costly or both. It is therefore necessary to look at the main features of nuclear propulsion plants to see how these plants match up to the conventional requirements.

The basic design of a nuclear reactor can be quickly described. Sufficient fissionable material, manufactured in the form of fuel elements, is assembled as a core, and so arranged that something slightly above critical size is achieved, i.e., such that a self-sustaining chain reaction is possible, in which more neutrons are generated by fission than are lost to the process by absorption and leakage. Control is exerted by rods of neutron absorbing material able to be moved into and out of the core. The fissioning of a U235 nucleus results not only in the release of high-energy neutrons and gamma radiations but also in the formation of fission fragments. These are retained within the cladding of the fuel and their radioactive decay results in the emission of further gamma and beta radiations. The heat generated in the core as a result of fission is removed by the coolant which itself is generally activated by neutron bombardment. It is therefore usually retained within a primary circuit (see Fig. 1) and gives up its heat through a heat exchanger to the working fluid of the secondary circuit which is used to drive the main propulsion machinery. The energy released by fission is such that the fissioning of 1 gm of U235 would give approximately 1 MW of heat for a day or 32,000 s.h.p.-hr, equivalent to the heat obtainable from 4 tons of coal.

It is seen then, that the reactor, plus its associated coolant, heat exchangers, and shielding takes the place of the boiler and fuel of the steam plant or the combustion chambers and fuel of the gas-turbine. Since there is as yet no worthwhile method of converting the energy of fission direct to electrical energy one still has to rely on conventional machinery such as steam or gas turbines to do the useful work. Reactor systems can be heterogeneous, as described above, or homogeneous, thermal or fast, and many other subdivisions are possible. Coolants may be gaseous (air, CO_2, N_2, He), light water or heavy water, organic liquids or a liquid metal. Moderating materials to slow the fission neutrons to thermal energies include graphite, light or heavy water, organic liquids and beryllium. The homogeneous system in which the fuel is dispersed in the coolant is not considered further, despite the attractions of low fissile investment and high fuel ratings, since such plants are complex, extremely bulky and cannot be readily foreseen in mobile form. Fast reactors, unlike thermal reactors, require no moderator and would result in plants with high heat ratings per cubic foot of core volume if one could remove the heat sufficiently quickly. They require high investment of U235 and are generally considered with liquid metal coolants such as sodium. Such a coolant has, however, disadvantages in its high chemical activity, its high induced activity and in the long half-life of its active isotope, resulting frequently in complex and bulky overall plants showing relatively little advantage, if any, over its thermal counterparts. It is important to realise that the power derived from any core is governed solely by the rate at which heat can be removed from it and this consideration, being dependent on the type of coolant used and fuel arrangement, will frequently determine the lower limits of size of a core rather than purely physics considerations.

The reactor systems of general interest for mobile applications are shown in Table I which gives their relative advantages and disadvantages. Table II gives in an approximate fashion (since size depends amongst other things on how much the fuel is enriched in the fissionable isotope, the type of moderator, the type of coolant and its heat transfer properties, and on fuel arrangement) a comparison of relative sizes and heat ratings. Figs. 2, 3, 4, 5 and 6 illustrate the basic flow diagrams and features of some of these plants.

REACTORS AS POWER UNITS

Having given the necessary fundamentals of fission reactors one can now study the dominant features associated with power from such systems. These are twofold:—

(*a*) Great endurance.

(*b*) Radiation.

The former obviously represents the main attraction, which when coupled with the fact that no air is required for combustion gives quite evident advantages in the submarine application. The advantages are not quite so obvious in other fields, however, unless the long endurance, low fuel consumption and potentiality of high power outputs result in the ability to do something which cannot otherwise be done, or results in overall economic gain. These points are further discussed in the later sections of the paper dealing with ship, aircraft and rocket propulsion.

Turning now to the second dominant feature, radiation, which always accompanies fission, we find that this is the compensating disadvantage. It has in fact such widespread effects in design, operation, maintenance, safety and costs of the nuclear plants, that it undoubtedly presents serious obstacles to the widespread mobile application of nuclear power.

The first repercussion from radiation arises in

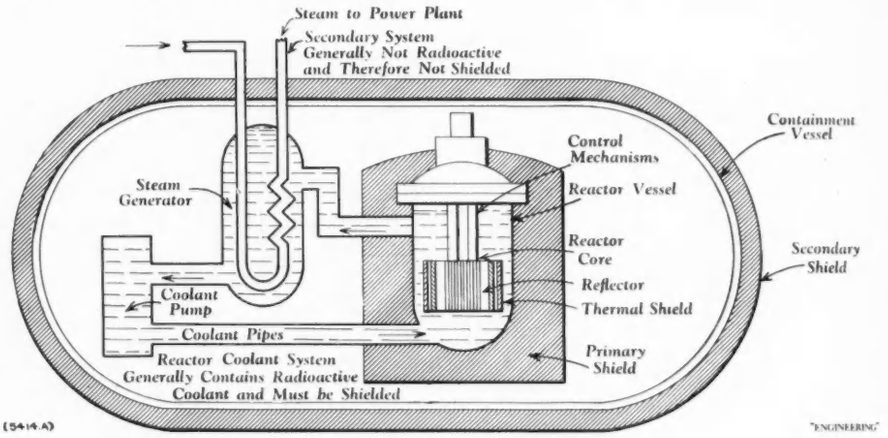


Fig. 1 Outline of reactor.

Units and Approximate Relations

(*a*) Source Strength:—Measured in Curies. 1 curie ≡ $3{\cdot}7 \times 10^{10}$ atom disintegrations per sec. (1 gm. of radium has a source strength of about 1 curie.)
1 curie produces 1 *r* per hour at 1 metre.

(*b*) Dose and Dose Rate:—The Röntgen (*r*) is used to measure quantities of radiation in terms of its ionisation of air.
A flux of about 10^8 photons per cm^2 per sec. of 1 or 2 MeV gammas ≈ 1 *r* per hr.
The maximum permissible level (mpl) of radiation or dose rate is 7·5 milli-*r* per hr. or 0·3 *r* per week. The total dose in 13 consecutive weeks should not exceed 3 *r*.
1 watt of energy release from fission ≡ 167 curies at 1 MeV.

(*c*) One weekly dose is given by exposure for 40 hrs. to 2,000 *n* per sq. cm^2 per sec. thermal neutrons (0·025 eV); 60 *n* per sq. cm per sec 1 MeV neutrons.

* Paper read before Section G, British Association, at Glasgow on Monday, 1 September, 1958.

the necessity to provide shielding to protect the crew, passengers and anyone likely to be in the vicinity against the neutrons and gammas emitted as a result of operation of the reactor. Whilst the latter is at power, intense neutron and gamma radiations result from the fission process; furthermore, gamma radiation will be emitted from the coolant and any activated corrosion products or primary circuit materials subjected to neutron bombardment. An example of the radiation intensity can be given by the fact that the neutron intensity at the surface of a high-powered reactor is about a billion times greater than the biologically permissible level; the gamma intensity is very nearly as great. One would in fact have to be about two miles away from an unshielded high-power reactor to lower the dose rate to the maximum permissible level (1 mpl). At 2,000 ft one would acquire a lethal dose in about $\frac{1}{4}$ hr and at 100 ft in about $\frac{1}{2}$ sec. Even $\frac{1}{4}$ hr after shut-down, one would still acquire a lethal dose at 100 ft in just over $\frac{1}{2}$ min.

Shielding reduces radiation intensity exponentially as may be shown by the fact that lead 2 in thick reduces a particular energy gamma radiation by a factor 10, 4 in thick by 100 and 6 in by a factor 1,000. Neutron attenuation is best accomplished by first slowing down fast neutrons by collisions with light atoms; water, hydrocarbons and some plastics are therefore particularly effective due to the hydrogen in their structure. Overall shield weights, which can range from under 100 tons to 1,500 tons or more, are dependent upon the initial size of the reactor, upon the specified radiation levels outside the shield, the materials used for shielding, the arrangement of primary circuit and other components (the latter being used to provide shadow shielding) and the type of coolant used. However, because on a weight basis most materials are roughly equivalent in regard to the heavy gamma shielding component, one can expect no more than 10 to 15 per cent weight saving by use of exotic materials such as tungsten or boron carbide.

Substantial weight savings can be achieved however in certain circumstances by permitting radiation to escape in certain localised directions where they can do no harm. In a submarine, for instance, use could be made of the fact that the reactor is below water level and radiation could be permitted to escape athwartships. The same principle would have to be used in aircraft reactors, and, provided precautions are taken against radiation scattered back as a result of collisions with the atoms of the surrounding media, this is a feasible method of weight saving. Coolant activities vary widely—for instance helium and hydrogen, if pure, would have no induced activity; air, CO_2 and water would have induced activity, resulting in the emission of 6·2 Mev gammas from the N16 isotope, which has a half-life of 7·3 seconds. Sodium on the other hand gives an isotope of 15 hr half-life with 1·38 and 2·78 Mev gammas. The activity of such a coolant might be several thousand times that of water during operation; furthermore the effect of the long half-life is noticed on shut-down, i.e. 1 min after shut-down the activity in the circuit will be several million times that of water and it would be several weeks before one could carry out maintenance on the circuit, except under the most difficult circumstances.

When the reactor is shut-down there will still be an intense gamma radiation resulting from the decaying fission products in the fuel, although this activity, which is accompanied by heat generation, decreases with time as the short-lived products die. Some of these products, such as caesium and strontium, have half-lives of many years; others such as iodine are volatile at certain temperatures. The general activity, and heat generated on shut-down, is dependent on the power history of the reactor prior to shut-down. For example, if one considers a 60 MW heat reactor, then after a prolonged period at full power, the activity of the fission products might amount to 3×10^8 curies, equivalent to several hundred tons of radium. The heat generated after shut-down would amount to 7 to 8 MW two seconds after shut-down, falling to just over 1 MW after one minute, and to $\frac{1}{2}$ MW some 5 hours later. The activity of the primary coolant circuit can be intense during operation, but if the activity is short-lived as in the case of water, air, or CO_2 then this rapidly dies away after shut-down, apart from that due to any long-lived activated corrosion products deposited around the circuit. This accounts for the split shielding technique commonly used, as shown in Fig. 1, in which the reactor is placed within a primary shield sufficient to attenuate the radiation to a level permitting entry for maintenance purposes to the primary-circuit compartment shortly after shut-down. The primary circuit itself is contained in a compartment which is further shielded (secondary shielding) to reduce the combined radiation from reactor and coolant when operating at power to acceptable levels outside the compartment.

TABLE I.—*Comparison of Reactor Types*

Reactor type	Advantages	Disadvantages
(1) Pressurised-water reactor (PWR)	Compactness: low weight. Small heat exchangers. Good stability, i.e. large negative temperature coefficient. Rapid response to power demands: Low pumping power: Proven in USA in submarine form, power station form and APPR. Being applied to USA's first surface ship "Savannah." Being developed in UK for submarine application. Some development possible by permitting local boiling.	Enriched fuel required. Poor steam conditions hence relatively low efficiency cycle. Corrosion problems. Relatively high pressure system, 1,500-2,000 lb per sq. in. Reflected in containment problems. Primary circuit active during operation. Mainly O 16 (n, p) N16 7·4 sec half-life, 6 MeV gamma.
(2) Boiling-water reactor (BWR)	Closely related to PWR technology. Lower primary circuit pressures. No pressuriser. If direct cycle used no heat exchanger required but main propulsion machinery may then require shielding. Possibility of natural circulation, avoiding pumps and valves in primary circuit. Prototypes operating USA.	Enriched fuel required. Corrosion problems. Primary circuit active. Main machinery active unless efficient separating system developed or indirect cycle used, when a heat exchanger is required and the advantages of compactness reduced. Control more complex than PWR due to steam voids in core and effect of power changes on these.
(3) Organic-liquid moderated reactor (OLMR)	Low-pressure primary circuit. Corrosion negligible. Good lubricating properties of liquid. Low induced activity. Large negative temperature coefficient.	Liquids unstable under irradiation and temperature above 400° C. Polymerisation products, make up and removal required. Suitable organics solid at NTP, requires trace heating. Fire risk. Hydrogen evolution. Poor heat transfer properties (about 1/5 as good as water for same pumping power). Enriched fuel required.
(4) Gas-cooled graphite-moderated	Natural uranium could be used although plant would then be unacceptably bulky. Reasonable steam conditions. No temperature limit imposed by coolant. Can increase specific output by higher gas pressures and gas temperatures, and by use of better structural materials such as Zr or Be canning, ceramic or cermet type fuels and enrichment. Proven system in power station form. Less energy in total primary circuit and containment may be easier than for PWR.	Large, heavy reactor. High pumping power. Large heat exchangers. Slow response. Poor heat transfer characteristics of gases. Wigner effects in graphite. Will require enriched fuel for mobile applications. Not yet developed in compact form suitable for propulsion.
(5) Gas-cooled heavy-water moderated	Natural uranium could be used. Much as for (4).	Large and heavy reactor although less than (4). Expense and limited availability of moderator. As for (4) except for Wigner effects. Complex design to separate moderator and coolant. Will require enriched fuel to make small enough for mobile purposes.

TABLE II.—*Approximate Relative Values of Size, Heat Loadings in Different Reactor Systems*

	Natural uranium	Natural uranium	Slightly enriched uranium	Highly enriched uranium	Slightly enriched uranium	Highly enriched uranium	Highly enriched uranium	Natural uranium	Slightly enriched uranium	Highly enriched uranium	Slightly enriched uranium
Reactor type	Graphite	D_2O	Graphite	Graphite	Water	Water	Organic liquid	D_2O	Graphite	Fast reactor	Boiling water reactor
	Gas cooled	D_2O	Gas	Gas High temp.	Water	Water	Organic liquid	Gas cooled	Sodium cooled	Sodium cooled	Water
Approximate relative core dimensions Diameter of right cylinder, ft	25 to 30	10 to 12	13 to 14	6	5 to 5½	2	6½	13 to 14	8	1	5 to 5½
MW per cu. ft (Heat)	$\frac{1}{100}$ to $\frac{1}{50}$	2	$\frac{1}{20}$ to $\frac{1}{10}$	2	1 to 1½	4 to 5	¾	½	$\frac{1}{5}$	30 to 50	1 to 1½
MW (Heat) per kgm U or MW (Heat) per ton U	1½	10 to 15	10 to 12	½ to 1	15 to 20	3	10 to 12	6	15 to 20	2 to 3	10 to 15

SAFETY PRECAUTIONS

A further feature—that of guarding against the accidental release of activity—is a major requirement. The repercussions of the accidental release of even part of the fission product activity if it occurred anywhere near a population centre would obviously be serious indeed. One has only to consider the effects of the release from Windscale to realise how much more difficult the protection problem becomes once radioactive particles become loose. Not only would there be the direct radiation from the fission cloud, the effect of which would decrease rapidly due to dispersion and decay, but the more serious possibility of ingestion through inhalation or by ground, crop and milk contamination would have to be faced. The remote siting of land-based power reactors is an example of the care taken at this stage of development even with relatively proven systems. Precautions will therefore have to be taken with the mobile reactor to contain the fission products in the event of accident conditions leading to their release from the core and primary circuit. This is obviously difficult with systems which have to face the increased risks associated with movement, and the aircraft case perhaps represents an extreme example of the problems of guaranteeing containment under all conditions.

The problem, of course, differs in detail with different systems. For instance, pressurised-water reactors require the coolant to be at 1,500 to 2,000 lb per sq. in to prevent steam formation; this represents a large amount of energy and if the primary circuit is ruptured and the water flashes into steam then the containment vessel will require to remain leaktight and sustain pressures several times higher than those resulting from failure of a low-pressure gas system. However, failures in pressure-water systems are generally less like explosions from the fragmentation point of view than high-

pressure air or gas systems. One also has to consider the risk of fire adding more energy to the system; organic liquids for instance are inflammable, uranium metal burns and it is not unknown for zirconium to burn even under water. The fact that heat continues to be generated in a core for a considerable period after shut-down has been mentioned; in order to ensure that this does not cause a partial melt of the core and release of fission products, a supply of coolant must be guaranteed under all conditions including loss of pumping power or even complete loss of main coolant from the system.

Further effects of radiation are found in the changes in properties induced in most materials by neutron and/or gamma doses. Plastics and rubbers harden and embrittle, resistances, conductances, capacitances change their basic values and lubricants break down. The properties of the important structural materials such as steel and graphite are affected, being demonstrated in the latter by the Wigner growth and stored energy, and in the former, in those steels exhibiting a brittle-ductile transformation, by a raising of the transition temperature. This may be raised as high as 50 to 100° C in certain steels by a total irradiation of fast neutrons of the order of 10^{19}. These harmful effects are temperature dependent and tend to be annealed out with high temperatures, but with the difficulties of inspection where activated materials are concerned—and the steel of a pressure vessel round the core would be very active indeed—it is obviously important for design to rest on a sound research basis.

One further peculiarity is worth mentioning. Some of the fission products decay to produce isotopes which capture thermal neutrons readily.

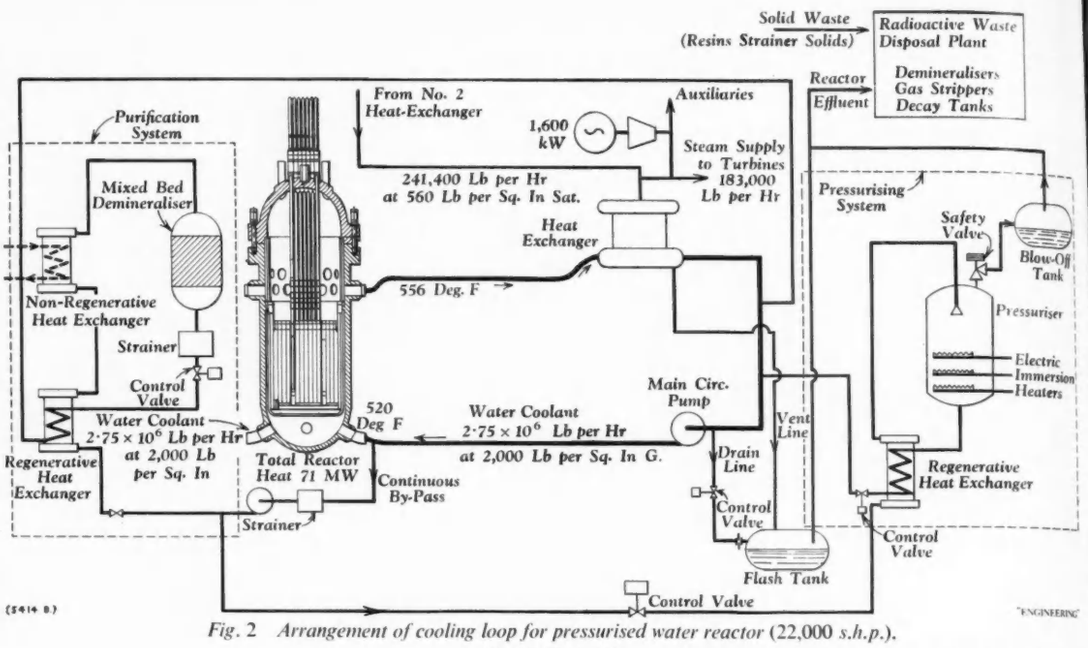


Fig. 2 Arrangement of cooling loop for pressurised water reactor (22,000 *s.h.p.*).

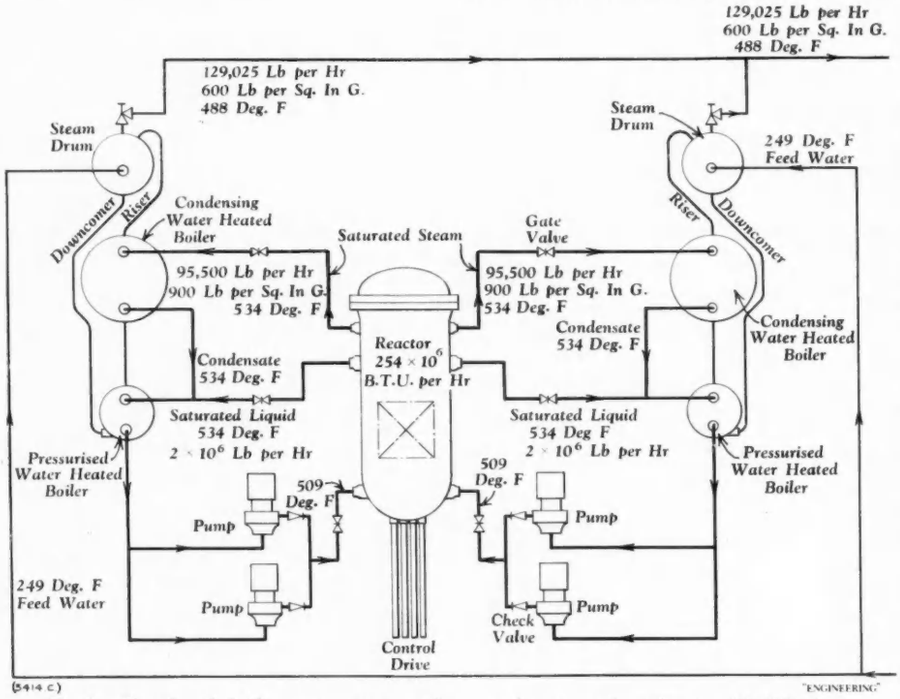


Fig. 3 Closed-cycle boiling-water reactor; diagram of reactor primary system (22,000 *s.h.p.*).

These are known as poisons and cause a loss of reactivity in the system which has to be catered for in the design of the core by building in more fissile material. Xenon 135 is the particularly troublesome poison in that, although the Xe concentration reaches equilibrium when the reactor is operating, when the reactor is shut-down the Xe steadily builds up for several hours because it continues to be formed as a decay product until it reaches a maximum, after which it slowly decreases. If allowance is not made for this then the state could easily be reached when after shut-down for a few hours, start-up would be impossible for some considerable time. The rate of power change can also be limited by this effect.

The inherent safety of a reactor system is, of course, a basic feature in design considerations. Each system will differ in its stability characteristics dependent on fuel, coolant and moderator materials and geometries, but basically the most stable reactor is that which has a large negative temperature coefficient, i.e., as the temperature rises, loss of reactivity occurs and the reactor tends to shut itself down. If it does not do this then complete faith must be placed in the integrity of the control system which is designed to shut the reactor down on the receipt of certain warning signals such as loss of coolant pump power, excessive temperature and power in the reactor, or excessive rate of power increase. The integrity of the fuel element is in itself a dominant design feature, since failure of the cladding could not only lead to escape of fission products into the primary circuit—a breach of

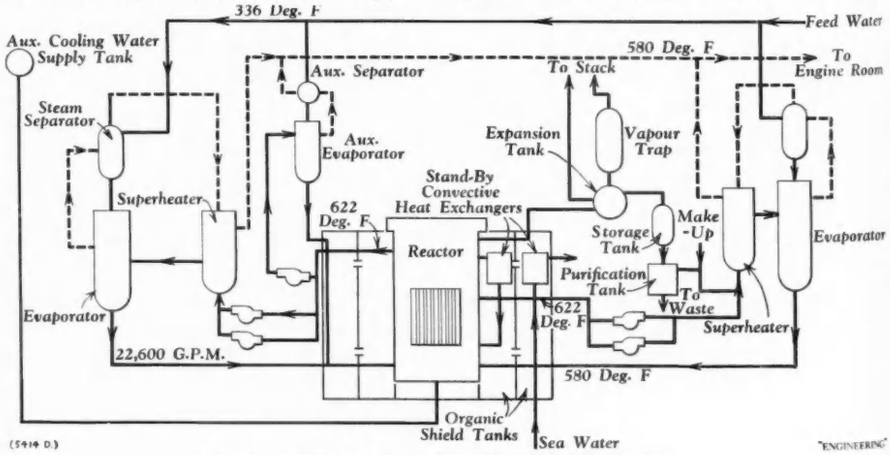


Fig. 4 Organic liquid moderated system (22,000 *s.h.p.*).

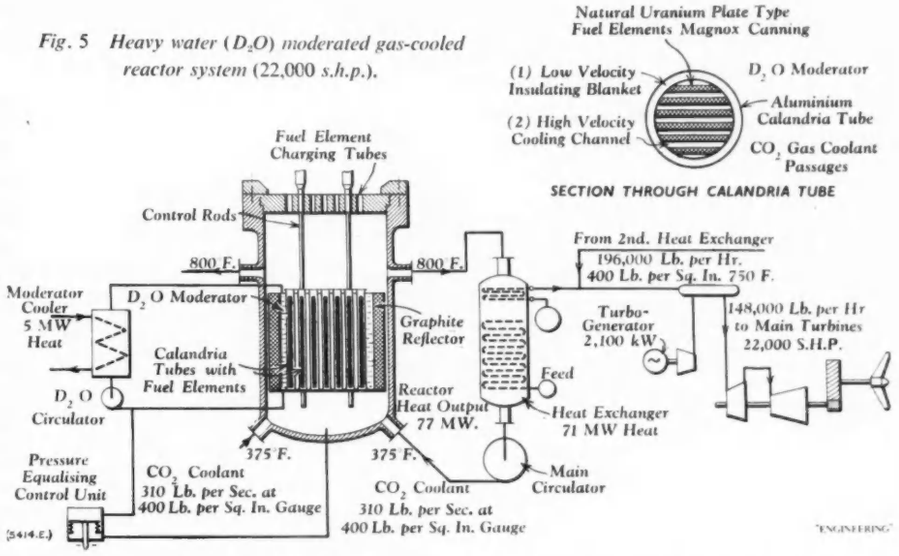
the first defence—but might also be progressive leading to further failures and ultimately a partial melting of the elements.

SCALE FACTOR

Turning now to the question of size and weight of reactor systems, it will be seen from Table II and also Table VI that, in order to achieve small size, one has to consider the use of fuel enriched in the expensive uranium 235 isotope. A small core means that a smaller pressure vessel is required, the total weight of shielding can be reduced and the containment vessel can be made smaller. This all means, in general terms, a reduction in capital costs and therefore a significant step in reducing overall running costs. A small core, however, is not the only parameter—the size of other auxiliaries such as steam generators, coolant pumps and pressurisers, the type of coolant used, and the effects of these on shielding all play a part in determining overall size, weight and cost. The use of small cores means that higher heat ratings and higher operating temperatures are demanded of the fuel elements. This in turn means that better fuel elements than those based on metallic uranium, as used in the Calder Hall reactors, are required. The use of uranium alloys or inert uranium oxides or carbides together with the use of other cladding materials such as zirconium, beryllium or stainless steels will enable one to achieve these higher temperatures and will also permit the fuel elements to be operated for greater lengths of time before they have to be withdrawn for reprocessing and recovery of the unburnt fuel. Such fuel elements will, however, require enrichment in the fissionable isotope and therefore, while capital costs and fuel reprocessing costs may be lowered, their use will tend to increase the direct fuel costs.

From the foregoing therefore it can be seen that the long, endurance, potential of nuclear power has to be set against the cost and practicability of meeting the safety, operating, and maintenance requirements dictated by irradiation and its effects. Sizes of systems can be brought to acceptable limits by enrichment, increased ratings and temperatures and by suitable choice of moderators and coolants and possible adjustment of external radiation levels, but, although these measures will reduce capital costs, fuel costs will rise when compared to land-based nuclear stations. The present background of reactor technology is that at present only two systems are known to be proven: the pressurised water reactor (PWR) is proved in its mobile (but highly expensive) form in the United States submarine programme, is now operating in power station form at Shippingport and is under development in the United Kingdom for submarine application; the graphite moderated CO_2 cooled power station reactor is proven in the United Kingdom by Calder Hall. No mobile adaptation of the latter, however, has yet been built. The boiling water reactor (BWR), which is virtually an extension of PWR technology, is promising in its prototype form in the United States. It is against this background that the application of nuclear power to the propulsion of ships, aircraft and other vehicles can at present be studied.

Fig. 5 Heavy water (D_2O) moderated gas-cooled reactor system (22,000 s.h.p.).

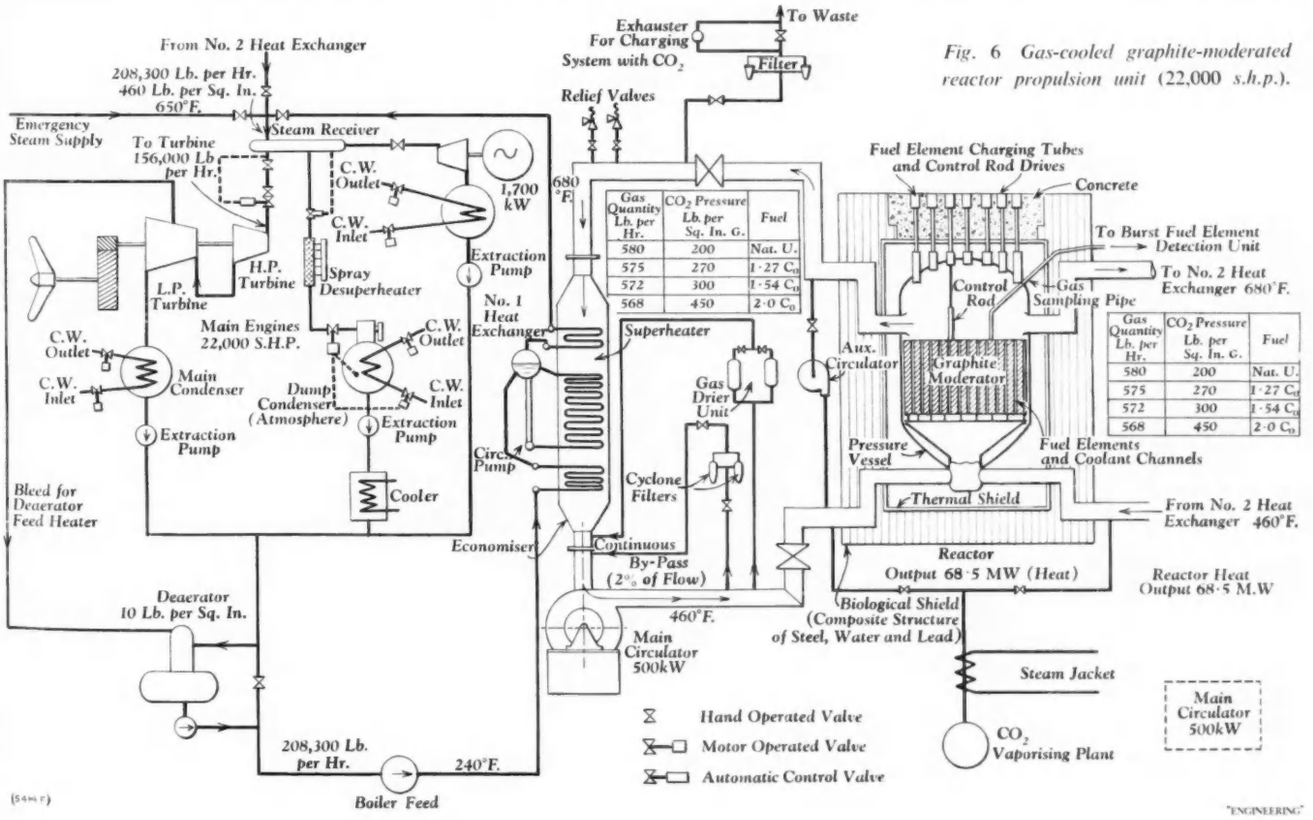

Natural Uranium Plate Type Fuel Elements Magnox Canning
(1) Low Velocity Insulating Blanket
(2) High Velocity Cooling Channel
D2 O Moderator
Aluminium Calandria Tube
CO2 Gas Coolant Passages
SECTION THROUGH CALANDRIA TUBE
Fuel Element Charging Tubes
Control Rods
800 F.
800 F.
From 2nd. Heat Exchanger
196,000 Lb. per Hr.
400 Lb. per Sq. In. 750 F.
Moderator Cooler 5 MW Heat
D2 O Moderator
Graphite Reflector
Turbo-Generator 2,100 kW
148,000 Lb. per Hr to Main Turbines 22,000 S.H.P.
Calandria Tubes with Fuel Elements
Feed
D2 O Circulator
Reactor Heat Output 77 MW.
Heat Exchanger 71 MW Heat
375 F.
375 F.
Pressure Equalising Control Unit
CO2 Coolant 310 Lb. per Sec. at 400 Lb. per Sq. In. Gauge
Main Circulator
CO2 Coolant 310 Lb. per Sec. at 400 Lb. per Sq. In. Gauge
(5414.E.)
"ENGINEERING"

SHIP PROPULSION

The feasibility and practicability of propelling ships by nuclear power is not in doubt. The performance of Nautilus, which steamed 69,000 miles on its first core charge, equivalent to some 2 million gallons of diesel oil, has amply demonstrated this. The fact that it cost nearly twenty times as much to do this as with ordinary fuel is not significant in terms of the operational advantages conferred on the submarine. Though it is an extreme case in which capital and development costs were high, and highly enriched and expensive fuel elements were used, the expense involved underlines one of the main problems preventing ready acceptance of nuclear propelled ships in general.

Before going into these problems in more detail it may be instructive to review the activities

Fig. 6 Gas-cooled graphite-moderated reactor propulsion unit (22,000 s.h.p.).



Gas Quantity Lb. per Hr.	CO_2 Pressure Lb. per Sq. In. G.	Fuel
580	200	Nat. U.
575	270	1·27 C_0
572	300	1·54 C_0
568	450	2·0 C_0

Gas Quantity Lb. per Hr.	CO_2 Pressure Lb. per Sq. In. G.	Fuel
580	200	Nat. U.
575	270	1·27 C_0
572	300	1·54 C_0
568	450	2·0 C_0

of various maritime nations in this field. Those of the United States are summarised in Table III, which adequately demonstrates the lead they possess. On the merchant side, the United State's first nuclear propelled vessel will be the passenger-cargo N.S. Savannah; most of the other design studies have been directed to the tanker application. Little is known of the USSR's marine activities with the exception of the construction of the icebreaker Lenin, which is likely to have been operational three years before the Savannah. The Lenin is reported to be of 16,000 tons displacement, 44,000 s.h.p., 500 ft long by 85 ft beam, with a 200 MW reactor giving her 18 knots. It can, however, be safely assumed that the USSR's technology is such as to enable her to build nuclear propelled submarines. France's nuclear submarine Q244 is well advanced. France has also announced plans for the construction of a 40,000 d.w.t. nuclear tanker of 20,000 s.h.p., the reactor plant for which is to be selected from PWR, boiling-water reactor (BWR) or gas-cooled systems. Detailed design studies of nuclear propulsion plants for merchant ships are being carried out by marine interests in Sweden, Norway, and Holland, and the latter is also reported to be preparing designs for a submarine. Poland has begun work on the design of a 20 knot 35,000 d.w.t. tanker using an organic moderated reactor, and Germany is carrying out detailed studies of a PWR system for a 22,000 d.w.t. tanker of 10,000 s.h.p. and of a closed cycle gas-turbine system. Reports from Japan indicate activity particularly in the tanker field where four basic designs are being studied ranging from 40,000 d.w.t. to 80,000 d.w.t. and including gas cooled boiling water and pressurised water reactor systems. The design of the 80,000 d.w.t., 40,000 s.h.p., tanker is stated to be completed and the keel laid.

Work in the United Kingdom has been concentrated on the submarine Dreadnought using a PWR of highly enriched fuel similar to the United States designs, and the construction of equipment for the land-based plant at Dounreay is now well advanced. A feasibility study directed to a possible surface-ship application is being carried out by the representatives of the Shipbuilding Industry and the Yarrow-Admiralty Research Department, in close association with UKAEA. A number of studies by the British Shipbuilding Research Association and private firms has also been made to date. No construction work has, however, begun. This survey thus indicates intense theoretical interest in most countries but little practical work on non-military nuclear ships except in the United States and USSR.

This last fact may simply be due to lack of technological ability at this stage of time, but there is obviously more to it than that and examination of the nuclear propelled surface ship's peculiarities may lead to the reasons. The principal effect of using nuclear power is to give long endurance to the ship, e.g., one charge of fuel might last three years or longer, which gives the possibility of low direct fuel costs. The costs of dealing with the radiation problems mentioned earlier in this paper, however, so add to the capital costs that these tend to dominate the issue. The type of ship most able to make use of the advantages and offset the disadvantages is one which has a high load factor, i.e., requires little time for loading and unloading, has long hauls enabling it to spend a high proportion of its time at sea, and for which fuel bills are heavy. The tanker with a usage factor of about 80 per cent, particularly the larger type, therefore has the greatest prospect of using nuclear power to its best advantage. The fast passenger liner with its demands for high power and large fuel requirements, despite its lower " time-at-sea " factor might also be potentially attractive in the long term. The shipping situation is therefore worth analysis.

MARITIME REQUIREMENTS

Fig. 7 illustrates the age distribution of the tanker and liner fleet of the United Kingdom and Table IV indicates the relative proportions of ships

TABLE III.—*Summary of USA Activity in Nuclear Powered Ships*

Naval submarines ..	(*a*) Nautilus.—First vessel to which nuclear propulsion applied. 1954. 3,200 tons. 319 ft. Twin screw PWR. (*b*) Seawolf.—3,300 tons. 330 ft. Twin screw. Sodium-cooled, beryllium moderated intermediate reactor. To be replaced by PWR. (*c*) Skate.—3,200 tons. 257 ft. Twin screw. PWR. (*d*) Skipjack.—2,700 tons. 252 ft. Albacore type hull. Single-screw, PWR. Type to act as Polaris Missile Launcher. (*e*) Triton.—5,450 tons. Twin screw. 2 × PWR. Radar picket. (*f*) Unnamed.—Small submarine. Contract to Combustion Engineering for PWR reactor to give 2,500 s.h.p. for 14 knots. *Total built, building, authorised or officially requested:*— 27 of which 4 now under construction will be able to fire Regulus missiles. *Future requirements:*— Bill now before Congress for authority to build further 100 nuclear submarines.
Naval surface vessels	(*a*) Cruiser.—USS Long Beach, keel laid December, 1957, complete 1961. 11,000 tons standard displacement. 2 × PWRs. (*b*) Aircraft Carrier.—Keel laid February, 1958, complete 1961. 8 × PWR. (*c*) Destroyer.—AEC seeking authorisation to obtain land-based prototype by GEC to evaluate advanced design, lightest PWR.
Other surface ships..	(*a*) N.S. Savannah.—Single screw, 22,000 s.h.p., passenger-cargo vessel, 21,840 tons loaded displacement, 21 knots, cruising radius 350,000 miles, PWR, under construction, operational 1960 to 1961. (*b*) Ice Breaker.—Bill before Congress to authorise building. (*c*) Passenger Vessel.—Bill introduced January, 1958, to seek authorisation of construction of nuclear powered superliner to replace SS America. (*d*) Other: (i) General Dynamics Corporation selected to develop gas-cooled reactor closed cycle, gas-turbine plant for merchant ship. Also carrying out design study of submarine tanker. (ii) Studies being undertaken on behalf AEC/M.A. of possibility of applying boiling water reactor to tanker (22,500 ton, 20,000 s.h.p., 20 knots) now under construction.

in the different size range. The tanker tonnage of the United Kingdom amounts to about 28 per cent of the total and liners account for over 50 per cent. While the dry-cargo section of the fleet appears to be declining, the tanker proportion in United Kingdom yards in September, 1957, amounted to over 50 per cent, i.e. 2,259,000 tons. Tankers built during the war years amount to about 30 per cent of those now in service and will require replacement between 1965 and 1970. In the world situation, there was a record 30 million d.w.t. tons of tankers under construction or on order, equivalent to nearly two-thirds of the aggregate world tanker tonnage in service. Nearly 80 per cent of these contracts were accounted for by tankers greater than 24,000 tons d.w.t., including over 10 million tons greater than 40,000 tons d.w.t. In the United Kingdom yards, of those under construction or planned, some 16 are between 40 and 45,000 tons d.w.t., seven are in the 45 to 60,000 tons and seven are greater than 60,000. If one considers only new tanker construction in the United Kingdom over the next five years, the power requirements might amount to a million s.h.p. or say 3,000 MW of heat installed. In terms of oil consumption this is equivalent to approximately 1½ million tons annually. There is thus some incentive to use fissile fuel and save fossil fuel, but to be seen in its proper perspective it must be compared with the land-power requirements where the United Kingdom might expect to have to import in the form of oil the equivalent

TABLE IV.—*Size Distribution by total tonnage of Liners and Tankers in U.K. Fleet mid-*1957

Gross tonnage range	Liners, 1,000 tons	Tankers, 1,000 tons
100–8,000	4,106	564
8,000–10,000 ..	1,792	1,683
10,000–15,000 ..	1,299	2,435
15,000–20,000 ..	360	474
20,000–25,000 ..	521	404
25,000–30,000 ..	465	25
30,000 and over ..	235	—

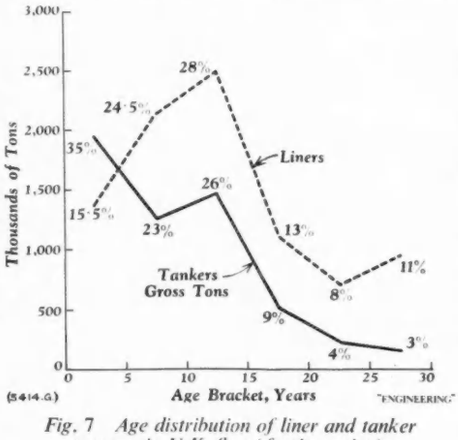


Fig. 7 Age distribution of liner and tanker tonnage in U.K. fleet (foreign going).

of 30 million tons of coal by 1965, over and above any imports for motor spirit.

In looking at the prospects for nuclear power in the tanker field one has to face the fact that the commercial objective must be to transport oil cargoes at minimum cost, and the effect on the cost per ton of oil carried is the prime factor in determining the merits of any propulsion system. Turn-round times of less than 24 hours leaves virtually no time for major repairs or the immobilisation of machinery for routine inspection and overhaul, and reliability is therefore of considerable importance. In this connection it is of interest to note that 283 of the 336 tankers of greater than 30,000 d.w.t. on order are steam-turbine driven, despite the lower fuel consumption of diesel ships. Table V gives some of the relative characteristics of conventional propulsion machinery for ships and Fig. 8 illustrates graphically the development improvements in these types made over the years. Table VI gives data for various types of nuclear reactor systems. It can be seen that on specific machinery weight alone the nuclear system cannot compete with the geared steam-turbine installation, but if one includes fuel weight then there is a good possibility that a distinct weight advantage would rest with nuclear plants in the larger merchant ships.

SHIELDING AT SEA

The above generalisation, however, has to be considered in relation to the more detailed difficulties. The problems of guarding against radiation hazards in providing containment and shielding, and integrity of fuel elements, control systems and primary circuit are accentuated by catering for the risks associated with storm, fire, collision, flooding, grounding, sinking, vibration and shock. It seems highly probable that one can achieve the necessary degree of protection but inevitably the capital costs are increased. Maintenance will generally be more expensive because of the radiation contamination of the primary circuit. Refuelling will require more complex and specialised arrangements than exist at present and there will be a need to provide special defuelling berths. means for remotely removing fuel elements or the complete core, transferring these to some coolant pond for the radiation to decay, and means for shielding and cooling these objects during removal (involving the removal coffins weighing some 20 tons for single fuel elements to several hundred tons for a complete core). Similar but lighter shielding and cooling facilities will have to be provided for transporting the fuel to the processing plant where the cans are stripped and the unburnt U 235 and any Pu 239 formed is recovered. Special safety precautions would also have to be observed during transport. The problem of defuelling will be exaggerated by the necessity still to guarantee nearly 100 per cent containment of any fission-product leakage. The necessary health precautions for crew and maintenance workers will have to be taken and presumably provision will have to be made for decontamina-

tion services both locally, for dealing with active components which might require servicing, and generally, in case any accidental release of activity should occur. Although crews can be expected to be comparable in numbers and ability to those in conventional ships, some will certainly require specialist training.

Another aspect of the question is the insurance rates which are still to be settled; while statistical analysis shows only a low probability of accident (for instance, one might expect some seven accidents per year involving ships of 20,000 d.w.t. or over, of which only a few would occur in or near populated areas) the fact that increased capital will be locked up in nuclear ships and there will be a risk, even though it seems remote, of widespread repercussions from a serious accident, seems bound to increase insurance rates. Furthermore, because ships are likely initially to be provided with only single reactors due to the poorer economics of multiple systems in terms of the weight and cost, some alternative conventionally fuelled power source will be provided, possibly in the form of a diesel or oil-fired boiler, to give say 1,000 s.h.p. for "get-you-home" purposes in the case of shut-down of the reactor.

The results of the foregoing considerations, therefore, lead one to conclude that of the three main factors determining costs per ton of oil or cargo carried, viz., capital costs and subsequent repayments and interest, basic costs due to insurance, wages, stores, dues, port charges, etc., and fuel costs (fuel investment, fabrication, burn-up and reprocessing) at least the first two are likely to be considerably higher than for conventional ships no matter what type of reactor system is used at present. A considerable number of studies has been carried out both in the United Kingdom and the United States on the relative economics of nuclear and conventional tankers and the conclusion to be drawn from all of these is that the total operational costs of the former will range from 10 to 40 per cent greater than the latter. These are complex studies, having to take into account capital costs, repayment and interest rates, machinery weights and load-carrying capacity, trip distances, oil fuel prices and prices of uranium, credits allowed for plutonium, service speeds and load factors, amongst others, and since much uncertainty exists in many of these items, particularly oil fuel and Pu 239 prices, it is not surprising that this degree of scatter appears in the results.

PROBABLE REACTORS

The principal factor leading to the higher overall costs is the greatly increased capital cost due largely to the machinery (including reactor, shielding containment, etc.) which may be some three times greater than conventional machinery costs. The repayments and interest on capital for the nuclear ship could in fact amount to some 60 per cent of the total operating costs. Fuel costs on the other hand, should be less than conventional fuel costs, but not perhaps as low as one might superficially expect by the time the investment charges are taken into account, and might account for some 20 per cent of the operating costs. Doubling the burn-up or life of the fuel elements might lead to perhaps a 30 per cent reduction in fuel costs but only an 8 to 10 per cent reduction in overall costs.

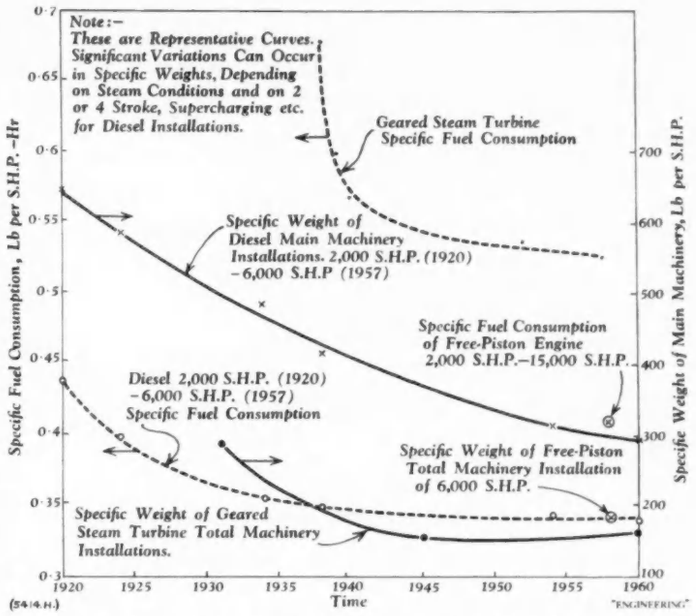


Fig. 8 Specific weights and specific fuel consumptions of marine engines with time. The curves are representive only and significant variations can occur in specific weights, depending on steam conditions and on use of 2 or 4 stroke cycles and of supercharging in diesel engines.

It can therefore be seen that it is essential to reduce capital costs and this seems most likely to stem from the use of basically simple systems of inherently small size with high specific heat ratings, in order to cut shielding and containment costs. The reduction of fuel costs is also important but here, if one accepts small size as a requirement, then one has to face up to the greater use of enriched fuel. A cheaper fuel than U235 is therefore required, as is a fuel cycle permitting the use of the cheap fuel in subsequent recharges. The time scale of building an advanced plant (in terms of present technology) to go to sea is such that the earliest the United Kingdom might achieve this is about the mid 1960's and it will not be long after this that Pu 239 will start to become available from the nuclear power stations. It can reasonably be expected that this fuel will be substantially less expensive than U235, and one should therefore expect mobile reactor designs to be based on its usage. Various fuel cycles can be considered but that involving plutonium recycle is promising in terms of low fuel costs. Here one might start with a low enriched thermal reactor and reprocess the charge at the end of its useful life to remove the fission products. The plutonium which had been generated in the U238 during operation would be left and make-up would be with cheap natural uranium before refabrication into the next fuel charge. If this can be achieved, and it should be possible with certain reactor systems even with the small mobile cores involving fairly high neutron leakage, then one might expect substantial savings in operating fuel costs.

When considering the relative merits of the various reactor systems one can see little prospect in the next ten years of advancing beyond those resting on the two established technologies, i.e., the PWR (and its variant the BWR) and the gas-cooled graphite-moderated reactor in a highly rated enriched form. The alternatives of organic liquid moderated reactors and heavy-water gas-cooled reactors would require intensive development and although the former offers the possibility of a considerable reduction in capital costs, arising from the lower primary-circuit pressure, it is difficult to see any appreciable advantages in the latter if it has to use enriched fuel to achieve the small size required. The PWR system requires enriched fuel, but in compact form so also will the gas-cooled system. The PWR requires a high pressure (1,500 to 2,000 lb per sq. in) and therefore expensive primary system and gives relatively poor steam conditions and low cycle efficiencies, but it produces a particularly compact plant. Moreover it possesses a high negative temperature coefficient. The BWR offers the prospect of reduced capital costs by the use of lower-circuit pressures of the order of 800 to 900 lb per sq. in, and improved steam conditions, but until a guaranteed highly efficient separation system is produced, enabling steam to be passed direct to the turbines without danger from escaping fission products, it is unlikely to offer great improvements in costs, size or weight. If steam can, however, be safely passed direct to the turbines from the reactor, such that one need not shield the propulsion plant, then this system will indeed be promising.

The gas-cooled system cannot expect to be as compact, but if beryllium is used as cladding material to permit gas temperatures of the order of 500° C and high gas pressures of say 600 to

TABLE V.—*Typical Operating Parameters for Conventional Ship Installations*

—	Specific weight, lb. per s.h.p.†	Specific fuel consumption lb. per s.h.p. per hr	Fuel cost pence per s.h.p. per hr.	Fuel carried for typical tanker voyage,* tons	Probable power range, s.h.p.	General remarks
Direct-drive diesel installations	300 (580)	0·35	0·3	2,800	Up to 25,000	Wide use, particularly for smaller powered ships, higher maintenance than for steam turbine. Approx. 160 s.h.p. per ft length of engine.
Free-piston gas-turbine installations	184 (509)	0·41	0·33	3,250	2,000-15,000	Few in service.
Geared steam-turbine installations	166§ (586)	0·53	0·42	4,200	For all marine powers above 6,000	Widespread use. Highly developed. Extremely reliable. Approx. 16 to 17 cu. ft machinery space per s.h.p. Cost from £70 per s.h.p. (smaller powers) to £60 per s.h.p. (20,000 s.h.p.).

Notes: * Fuel weights for 22,000 s.h.p. (47,000 d.w. tanker), 17 knots, 11,000 mile voyage United Kingdom to Persian Gulf.
§ Specific weights for steam plants for Naval vessels considerably lower. Probably less than 50 lb per s.h.p.
† Specific weights given in brackets include fuel weight.

TABLE VI.—*Comparative Parameters for Different Reactor Systems*

Reactor system	PWR Savannah type	PWR highly enriched submarine type	Calder Hall type	Slightly enriched Calder Hall, 300 lb per sq. in., 400° C	Enriched, gas-cooled, closed-cycle gas-turbine 550° C gas temp.	Heavy-water moderated, gas cooled	Enriched organic moderated and cooled
Specific weight of machinery, lb per s.h.p.	300-350	150-200	2,000	500	150-200	370	200
Shield weight as percentage of total machinery	30-35	20	55	45	40-50	40	40
Specific costs, reactor and machinery	£170 per s.h.p.	—	£250 per h.p.	£160 per h.p.	*Note:* Figures approximate only. Dependent on many factors. Suitable for installations of about 20,000 s.h.p.		

1,000 lb per sq. in are used, then a high efficiency and compact steam plant would result. The reactor itself, however, would be costly and fuel elements quite different to the Calder Hall type would be required, viz., either oxide, cermet, or ceramic rather than metallic. There would also be the possibility of CO_2-graphite reactions at the higher temperatures. To enable gas-turbines to be used in the propulsion plant one would have to proceed to gas temperatures of the order of 700° C to 750° C, thereby departing from the Calder concept and be in that class of reactors known as high temperature gas-cooled (HTGC), reactors in which a high degree of dispersion of the fissile material in the moderator is used in order to achieve the necessary heat transfer surface. The gas-cooled graphite moderated system has not a good negative temperature coefficient and this may be important when considering the use of plutonium. Although the physics of the plutonium systems are not fully evaluated, it is known that this element possesses a strongly marked capture resonance for neutrons at slightly above thermal energy and there is therefore the possibility that a strong positive temperature coefficient due to the fuel would predominate unless there was a compensating negative coefficient elsewhere in the system. The use of plutonium would therefore seem to be preferable in those systems in which the moderator, and therefore the neutron, temperature, remained low, as in liquid moderated reactors.

NAVAL VESSELS

Before leaving the question of nuclear power and ship propulsion one should also look at the Naval surface vessel requirements since it is here that one might find the earliest economic justification for building and operating a nuclear surface vessel. The operational advantages of nuclear surface warships are not as obvious as for submarines since no substantial decrease of vulnerability is conferred on them; the fact that they are on the surface renders them more detectable than submarines and therefore more open to attack. Nevertheless the advantages of independence of oil supplies, fewer worries about economic ship speeds, in giving greater defence potential in shipping protection and possibly offering the promise of better ship designs by eliminating boiler air intake and exhaust outlet, are attractive and one might be prepared to pay an extra price to achieve them, although much lower than in the case of the submarine. In other words one is likely to require a unit which at least approaches in economic terms the commercial requirement. The real costs of operating surface vessels in the Navy are not available, but they may be expected to be higher than commercial vessels and therefore be closer to the predicted costs of nuclear operation at the moment. In terms of operational value, however, it is of little use to apply nuclear power to one warship, as one must in the preliminary stages of development; if, however, a fast, large tanker was nuclear powered and able to serve in the fleet replenishment role, it would be able, in part, to confer its advantage of increased bunker capacity and speed to a large proportion of the fleet. The aircraft carrier, whose defensive and offensive capabilities are limited more by the aviation fuel it can carry than the oil fuel, would be particularly likely to benefit.

The prospects of the large submarine tanker have been frequently mentioned and this, if it is ever required, would probably only be made practicable by the use of nuclear power. It appears that these tankers will show to no advantage over surface tankers until high speeds are reached, when the wave-making resistance of the surface tanker becomes appreciable. It is probable in fact that real advantages would only show at speeds of the order of 50 knots and over and to achieve this vessels might require more than a million s.h.p. When this stage is reached it is probable that the nuclear plant, shielded only by the oil fuel carried, would be the one method of achieving such power. At such speeds it is likely that propellers would be replaced by the jet type of propulsion device such as the hydroduct, thus paralleling aircraft development.

In summary then, it can be seen that at present there is no commercial incentive to apply nuclear power to surface vessels. There are good long-term prospects of getting economic justification in the large tanker application but to do this one must substantially reduce capital plant costs by reduced size and by the use of as simple and safe a system as possible. Fuels of long life and high burn-up, and higher heat ratings, must be sought and to assist in achieving these aims one must contemplate the use of enriched fuel and hence must look to the cheaper plutonium to provide this.

The intangibles associated with ship operations on nuclear power, particularly in the cost of the support facilities, can hardly be evaluated theoretically and the fast fleet replenishment tanker with the ability to perform a useful and probably economic job appears to be the best stepping stone in acquiring these data. Until we actually build and put such a ship to sea few real advances can expect to be made. If the type of reactor chosen for this application is based on water technology, perhaps on grounds of plutonium usage, then the United Kingdom would be in the position, because of its power station developments, of being able to

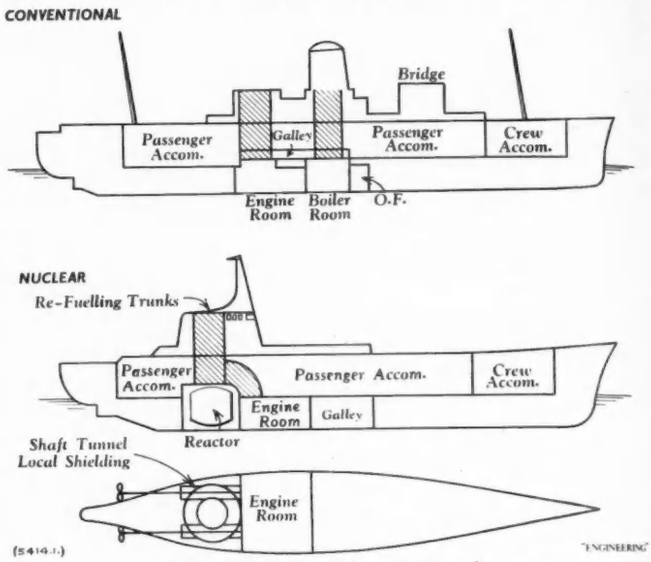
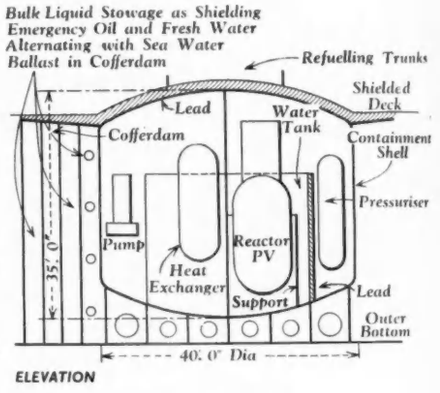


Fig. 9 Arrangements for passenger liners.

TABLE VII.—*Characteristics of U.S.A. Reactor Design Proposals for Ship Propulsion, 22,000 s.h.p.*

Designer	Babcock and Wilcox	American Machine and Foundry (AMF)	Atomics International	General Atomic
Type	Savannah PWR	Boiling water	Organic moderated	Gas-cooled (CO_2) Zirconium-hydride moderator
Full power core MW (Heat)	74	74·5	70	55
Endurance F.P., hr.	14,400	7,600	13,500	10,800
Temp. coefficient, 10^{-5} per °C	−50	−11	−12	−1·7
Core	Cylinder 61 in dia. × 66 in high	Cylinder 57½ in × 60 in	Cylinder 72 in × 72 in	Hexagon 68 in × 66 in
U 235 Kgm and enrichment, per cent	330 + Boron as burnable poison 4	160 9·5	245 1·58	120 + Boron as burnable poison 28·6
Coolant flow, 10^3 lb per hr	8,000	4,190	10,000	1,230
Primary circuit pressure, lb per sq. in abs	1,750	900	35	2,000
Outlet temp, °C	271	279	328	700
Fuel element type	UO_2 pellets in stainless steel tubes ½ in o.d.	UO_2 pellets canned in Zircalloy 2	Plate	UO_2/SS cermet clad in SS rod type
Control rods	21 cruciform Silver-cadmium-indium alloy (?)	Cruciform 12-B-SS 4-Hf	Cylinder 16-B/SS	Hexagon 25



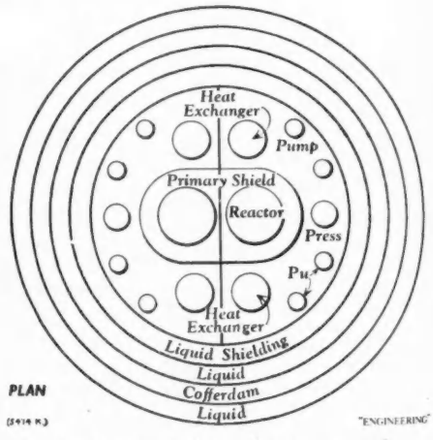


Fig. 10 Power unit for nuclear passenger liner.

Hypothetical nuclear passenger liner shown in Figs. 9 and 10. 30,000 tons displacement. 24 knots. Twin-reactor, twin-screw, 20,000 s.h.p. per shaft. PWR system 5 ft dia. core. Pressure vessel 9 ft dia. × 25 ft high overall. Containment vessel 40 ft dia. on vertical axis.

(*a*) Primary shield:—radial water blanket contained in steel tank, lead clad on outer face. Tank acts as support for pressure vessel and is integrated with hull — 150 tons

(*b*) Secondary top shield:—lead/polythene deck over containment vessel — 250 tons

(*c*) Secondary radial shield:—(i) using bulk liquid stowage, fuel and water in concentric tanks — 1,500 tons liquids + 200 tons containment + 200 tons structural wt.

(ii) If 6 in lead plus polytehene 8 in thick used on outside of containment vessel — 1,250 tons but 3 times as costly.

evaluate two most promising systems, and thereby fully exploit the nuclear power application in this and comparable fields when the time was right to do so.

Figs. 9 and 10 illustrate the N.S. Savannah and a hypothetical passenger ship application, the latter being included to demonstrate a possible plant layout for a dual reactor system. The nuclear plants are likely to be situated as much below the water line as possible on safety and weight disposition grounds. The hypothetical passenger ship is taken to be about 30,000 tons displacement and 40,000 s.h.p. and, as shown makes use of the liquid stowage, e.g., 500 tons emergency fuel oil and 1,000 tons of fresh water in the secondary shield arranged in concentric tanks around the containment vessel. This arrangement would afford a useful collision protection. By the use of such liquid stowage, by keeping the reactor compartment as far removed from crew and passenger quarters as possible and by minimising crew time spent in the vicinity of the reactor, it should be feasible to get a nuclear ship of similar speed, payload and amenities as its conventional counterpart on a hull displacing some 10 to 20 per cent less. Table VII gives the basic parameters of a number of ship reactor systems under investigation in the United States.

AIRCRAFT PROPULSION

It is immediately obvious that the most serious disadvantage of a nuclear powered aircraft arises from the crash hazard and the associated probability of release of fission products. The advantage of long endurance alone is not immediately obvious and one is hard put to see therefore any incentive, at least in the commercial field, to applying nuclear power to aircraft for fare-paying passengers, particularly when considering the potentiality remaining in conventionally fuelled aircraft.

One cannot dismiss this quite so briefly, however, and it is as well to look a little more closely into the implications. The demand for aircraft propulsion plants to possess the utmost reliability is overriding: the demands for compactness and lightweight are even more onerous than for ship plants, and these requirements are again accompanied by the need for low first cost and ease of maintenance and low running costs. Civil aircraft due to come into service soon will have a maximum take-off weight of about 300,000 lb, cruise at 550 m.p.h. over a stage length of about 3,000 miles, require a cruising thrust of 20,000 lb and a take-off thrust of 70,000 lb. The structure would probably account for about 30 per cent of the all-up weight, the engines about 8 per cent, the fuel 45 per cent, and the pay load between 10 and 15 per cent. Looking further ahead a supersonic version operating over the same range might have the following figures: all-up weight 400,000 lb, speed 1,200 m.p.h., a cruising thrust of 60,000 lb and a take-off thrust of 150,000 lb. The structure would account for about 25 per cent of the all-up weight, the fuel 55 per cent and the payload less than 10 per cent.

Nuclear plants for the same type of aircraft would in the subsonic version require a reactor of about 120 MW of heat to produce the cruising thrust. This would need an investment of some 60 kgm of U235 and confer a range of about 100,000 miles before reprocessing of the fuel elements was necessary. The structure weight would account for 30 per cent of the all-up weight, but the reactor plus shielding, plus the turbo jet units would now account for about 60 per cent of the total weight, and, of course, would no longer be distributed but concentrated in the region of the reactor and around crew and passenger positions. Cost could be expected to be in the region of £4 million. The supersonic version would require a core producing some 600 MW of heat and an investment of perhaps 300 kgm of U235, giving a range before refuelling several times the subsonic version.

AIR-FRAME REQUIREMENTS

The structural problems will arise mainly from the concentrated shielding and engine weights, the magnitude of the problem perhaps best being illustrated by some figures. The lethality of an unshielded reactor was demonstrated in the earlier section of the paper: if one now envisages an aircraft with the crew 100 ft from an unshielded 300 MW reactor, the weight of shielding round the crew compartment to reduce the dose rate to ten times the maximum permissible level might amount to about 80 tons. This weight is based on providing little or no attenuation of radiation in all other directions. Doubling the reactor power would not appreciably affect this. Allowing the dose rate to go up to 100 mpl's would decrease the shield weight by perhaps 20 per cent. If the reactor was fully shielded in the crew direction but only partially shielded elsewhere, the shield weight would probably amount to something over 110 tons. Probably minimum shielding will be achieved by the split technique in which some shielding is placed round the reactor and some round the crew compartment. Strict attention will have to be given to the total radiation dose acquired by the crew and it is probable that only a limited number of hours flying in a nuclear aircraft would be permitted. Crew cabin layouts are bound to be cramped since each extra foot on dimension would mean a disproportionate shield weight increase; visibility is likely to be worse than in conventional aircraft because of the scattering properties of air and the reflection back into the compartment of escaping radiation, and in fact the provision of windows may be a major difficulty. The jet units will probably have to be fuselage mounted in the vicinity of the reactor to reduce heat distribution problems, and, since take-off and landing weights will be virtually unchanged, the landing gear will have to be of more robust construction than for conventional aircraft, and will also probably have to be sited in the fuselage near the power plant and centre of gravity of the aircraft.

FAILURE IN THE AIR

The structural design will therefore present many problems, perhaps not least of which will be those associated with uncertainties in total shield weights. Because of the considerations of reliability, safety, and the greatly increased power requirements for take-off it appears probable that conventional chemical fuel and perhaps even additional turbo-jet units will be required for take-off purposes, and for use when landing and possibly emergency cooling. There are, therefore, great problems associated with nuclear installations and one must not overlook the support facilities required in the way of specially shielded vehicles for crew disembarkation and loading, special bays and pits for removing the active reactor system and special ground support equipment. In the initial stages at least, runways and airfields would require remote siting, further adding to cost and time of transit from city to airport.

The hazards of a crash are, however, dominant. Statistical figures for crashes mean nothing in a case where even one crash, which in a serious case might scatter most of the heavy structural items over a ½ to 1 mile radius, and lighter items over a linear spread of some 5 miles, could release so much radio-activity. Even if the core remained intact, there would almost certainly be loss of coolant and therefore a distinct probability of fuel elements melting from the decay heat. Ground contamination would be intense and special arrangements would probaby have to be made to remove the contaminated earth. It is for these reasons therefore that it seems that nuclear-propelled passenger aircraft, even if they are confined to sea flights only, are unlikely to be realised in the United Kingdom for many years, particularly when one still sees much development potential remaining in chemical fuelled aircraft propulsion units. Cruising speeds are now steadily approaching the 600 m.p.h. mark and it does not seem beyond the bounds of probability that conventionally fuelled engines will be able to give passenger transport at 1,200 m.p.h. with the range considered necessary.

Militarily the advantages of long endurance and or range may be worthwhile, and if so then the type of reactor likely to be chosen would probably be an inherently simple system involving a high-temperature air-cooled core in which air compressed by the turbo-compressor is passed through the core, heated, passed to the compressor turbine and then exhausted through the conventional jet. The use of sodium as the coolant, despite its high heat transfer rates and the potentiality of requiring, with a fast reactor, a core of only ¼ the volume of the air-cooled thermal core, has several drawbacks; disadvantages include activity, requiring one or more heat exchangers, fire risk, and the mechanical standards required to ensure leak tightness. For these reasons it does not appear a promising first line of attack at least. In order to achieve reasonable turbine performance one will be striving for coolant temperatures of the order of 800 to 850° C, which implies fuel element surface temperatures of the order of 1,000° C. Dispersed type ceramic or cermet type elements clad in steel will probably be required, with a moderating material of beryllium oxide or graphite. One might then expect to achieve 10 to 12 MW heat per cu. ft of core and a fuel rating of 2 to 3 MW per Kgm of U235.

Although the use of fissionable material could confer an unprecedented endurance or range on aircraft it must be realised that the number of days operation from a core is quite limited, perhaps of the order of 50 to 100 days, before the fuel must be removed and reprocessed. This high turn-over means an extremely heavy investment in fissionable fuel, equivalent to the airline operator buying at one purchase many years supply of chemical fuel.

Summarising then, it will probably be feasible for military type aircraft to be nuclear powered. The shielding problem for commercial aircraft is significantly greater and, even without the psychological drawback in regard to the passengers, such aircraft are much more remote. The fact that some 10 years of concentrated scientific and technical effort would be required to get one to the stage of building a flying prototype, the hazard potential and amount of locked-up capital and fuel investment required, and bearing in mind the development potential still remaining in chemical fuelled engines, lead to the conclusion that there is little prospect of nuclear power being applied to these passenger aircraft in the United Kingdom for many years to come. Fig. 11 illustrates a light-water moderated and cooled 1,000 kW (heat) reactor made by General Dynamics Corporation of the United States. This was the first nuclear reactor ever to go critical while airborne and did so in a B36 in September, 1955. It was specifically designed for shielding experiments and enables 26 different shield configurations to be studied.

ROCKET PROPULSION

Little can be said as yet about the possibility of applying nuclear power to rocket propulsion except that, in perhaps ten years time, the limit of development with chemical fuels may have been reached and nuclear power has the potentiality of carrying one into the next development stage. The range of rockets depends on the velocity imparted, which in turn depends on the exhaust velocity of the gas and on the ratio of the mass of the rocket at take-off to its mass with empty fuel tanks. The exhaust velocity is a function of the pressure, temperature and physical properties of the combustion gases. High combustion temperatures and gases with low molecular weights are necessary to achieve the exhaust velocities required. At present, with combustion temperatures between 2,000° C and 3,000° C, exhaust velocities between 6,500 and 8,000 ft per sec can be achieved. If one used liquid hydrogen and liquid oxygen about 3,000° C and 13,000 ft per sec might be achieved. One might then use liquid fluorine instead of oxygen and get some 4,000° C and 14,000 ft per sec. This then seems about the limit of chemical propellants, unless a method can be devised of storing free radical propellants, of

which an example is atomic hydrogen. If the two atoms of hydrogen are recombined to form the molecule, theoretically one could release about 15 times as much energy (on a mass basis) as is the case with combustion of hydrogen and oxygen. This would yield temperatures of the order of 5,000° C and velocities of about 40,000 ft per sec. As yet no practical method of storing this extremely unstable form of hydrogen has been found, but if it becomes practical it would be a strong competitor to the use of atomic energy in this field.

The only practicable method of using atomic energy that can be foreseen to-day involves the carrying of the reactor coolant, which, stored in liquid form, would be passed through the reactor core, heated to a suitable temperature determined by the structural materials, and then expanded out through the usual convergent-divergent nozzle. Again a fluid of low molecular weight would be required and it is also probably that it would be hydrogen. In order to obtain worthwhile advantages in velocities, reactor temperatures of the order of 4,000° C would be required. The only hope here lies in the use of dispersed fuel in refractory materials, such as the carbides of various metals, forming a porous core to give the necessary heat transfer area. The thermal output of a core would have to be of the order of 100 MW per ton of thrust developed for exhaust velocities of the order of 32,000 ft per sec. The fact that the coolant has to be carried is a serious disadvantage and one therefore sees the reactor as simply replacing the oxidant and combustion chamber of the chemically fuelled rocket (see Fig. 12). However, no other remotely feasible way is to be seen, with the exception of the free radical system, of increasing the exhaust velocity to the extent whereby rockets with reasonably low mass ratios—and therefore useful pay loads—can be sent, say, to the moon. The rockets would almost certainly require to be practically unshielded and the degree of reliability to guarantee no unpremeditated return to earth presents probably as big a problem as development of a nuclear power plant itself.

OTHER TRANSPORT

Although from the purely feasibility aspect there is little doubt that if sufficient effort was put into the project one could produce a nuclear powered locomotive, there appears to be very little object in so doing. A gas-cooled reactor producing 6 MW heat and gas at temperatures of 700° C, using probably CO_2 or N_2 at 20 atmospheres, and highly enriched UO_2 fuel elements clad in stainless steel, could be used with a closed-cycle gas-turbine/electric generator plant to produce about 1,500 h.p. The core, containing perhaps 30 Kgm U235, could be housed in a vessel of about 7 ft diameter, and would require to be fully shielded, thus weighing several hundreds of tons. The development cost would be many millions of pounds and capital, maintenance and running costs would all be 3 to 4 times as great as for conventional locomotives. Although it could run for 2 to 3 years without refuelling one can see little intrinsic merit in this, so that even without considering safety questions one can rule this out as a practical proposition in the United Kingdom. The application to cars or lorries is also impracticable.

Although the direct application of nuclear power has practically no prospect in these two fields, one should not forget that indirect application is feasible. Here one would generate electricity safely and economically in nuclear power stations and feed it, possibly by overhead lines, to the electrical power plant in the locomotive.

CONCLUSIONS

There is little prospect in the next ten years of nuclear propulsion plants being built and operated by the United Kingdom in anything but the ship application. Even in this latter field there is at present no commercial incentive, nor any urgency from the point of view of conserving oil supplies when compared with the land energy requirements. There are, however, good prospects of economic parity with conventional plants being ultimately achieved in the large tanker application. There are also reasons to believe that, within the next seven years, plants could be produced which would, if applied to Naval support tankers, be economically comparable with conventional plants if one takes into account the operational advantages derived from them. This application could therefore be a most valuable link in the development process, giving some early usage and defining the problems of nuclear ship operations, whilst leading ultimately to the more widespread commercial application involving compact reactors operating with enriched fuel on a plutonium system.

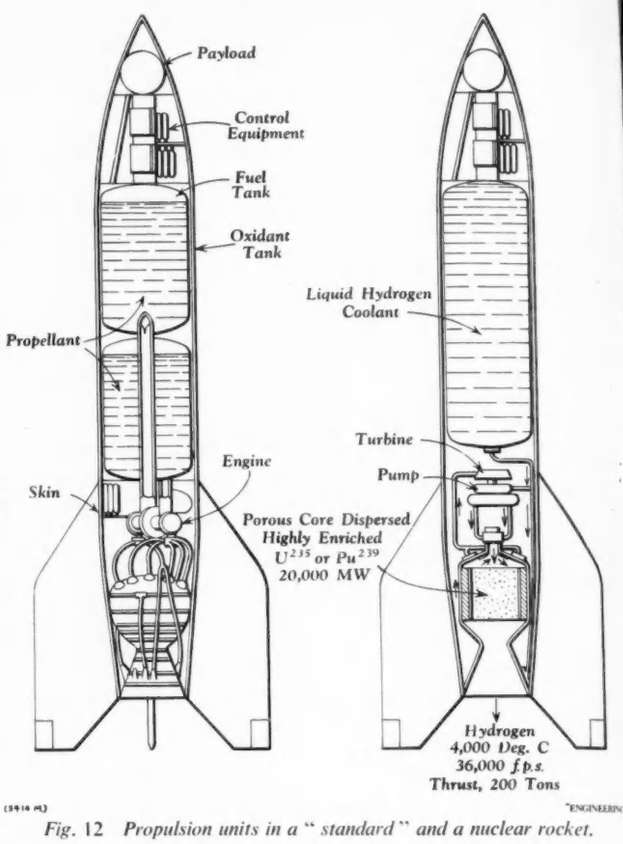


Fig. 12 Propulsion units in a "standard" and a nuclear rocket.

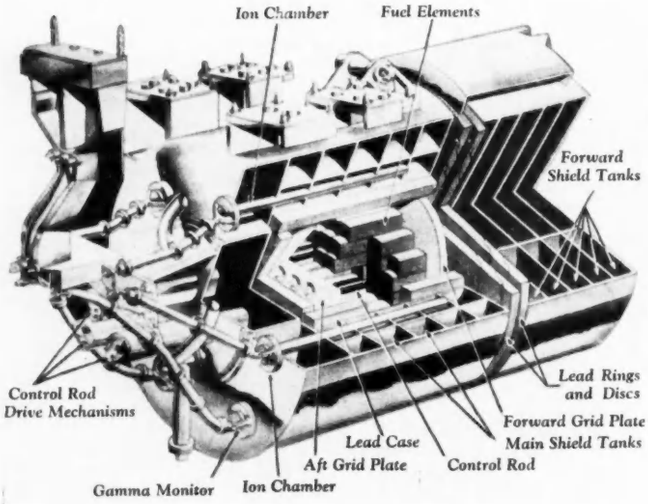


Fig. 11 ASTR (cutaway). For characteristics, see foot of column 3.

Acknowledgments

The help of colleagues in the Admiralty, AERE, RAE, and of Yarrow and Company Limited, particularly those in the Naval Section of AERE, is gratefully acknowledged. Figs. 2, 5 and 6 were provided by the courtesy of Dr. T. W. F. Brown of Pametrada. The views expressed in the paper are those of the author.

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Characteristics of ASTR (see Fig. 11) :—

Power output (heat)	1,000 kw
Thermal neutron flux—	
average	$6{\cdot}3 \times 10^{13}$
maximum	$1{\cdot}2 \times 10^{14}$
Fuel element	
type	plate
composition	U-Al
cladding	Al
Fuel loading	4,800gm highly enriched U
Core configuration	right cylinder
Control rods—	
number	3
composition	cadmium-lined steel
worth	2·00 dol each shim, safety 0·25 dol regulating
Coolant/moderator	
type	light water
flow	500 gal. per min.

Continuing **Research and Development**

RADIO AIDS TO NAVIGATION*

POSITION FINDING BY RADIO

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From the early days of the application of electromagnetic waves to radio communication interest has been shown in using such waves to fix the position of an observer. In his early classical experiments Heinrich Hertz used reflecting mirrors to project the waves in a specific direction and he also used circular loops to receive the waves and demonstrate directional properties of such loops. At the beginning of the present century one of the most important applications of radio—then called wireless—was for telegraphic communication with ships at sea. The need to determine the direction from which a ship's signals were being received, particularly in times of distress, stimulated early experiments in direction finding by reception.

It was during the period of the first world war (1914-18) that the radio direction finder was developed into a reliable instrument. This was largely the result of the introduction of valve amplification into radio reception, which both increased the range of reception and also brought to light faults which had been overlooked in earlier designs. Such a system of direction finding is reversible, and by feeding a suitable rotatable aerial system from a transmitter a directional property is given to the signals and the bearing of the transmitter can be determined with a simple radio receiver. To obtain a position fix, cross-bearings must be obtained from two such directional transmitters.

BASIC METHODS

The introduction of radar just before the second world war (1939-45) provided a means of measuring the distance between a transmitter and receiver, so that the combined observation of bearing—or direction—and distance—or range—enables the position of a receiver to be fixed with the aid of a single transmitter. To do this successfully, however, involves an accurate method of measuring the time of transit of the waves between transmitter and receiver, and this means the equipment of the receiver with some relatively complicated apparatus.

There are thus three basic methods of approaching the problem of determining the position of an observer. The first is analogous to the use of the surveyor's theodolite in observing the direction of two or more fixed marks in known positions. In the case of radio the observer has a direction finder which enables him to take cross-bearings on the waves radiated from two or more transmitting stations in known positions. This method may also be applied in reverse by using two or more direction finding stations to take bearings on a radio transmitter whose position it is required to determine.

The second approach to the radio problem transfers the directional properties of the radio aerial system from the receiving to the transmitting station. In this case, the radiation characteristics of the transmitter vary with direction, and by mechanical or electrical means these characteristics are made to rotate continuously through a specified arc or the whole 360° of azimuth. An observer at a distant radio receiving point having a knowledge of these characteristics can determine the direction of the transmitter from the signals he hears as the pattern rotates, or sweeps over its assigned sector.

The third method of determining position by radio makes use of a knowledge of the speed with which radio waves travel along the ground or through the atmosphere. To do this we may either emit the waves from two or more radio transmitters in short, accurately synchronised pulses and measure the difference in time of arrival of the waves at the receiving point: alternatively, sets of synchronised continuous waves are emitted and the phase difference between the waves arriving from fixed pairs of transmitters is measured at the receiver. In both techniques the measurement of very small time—or phase—difference is involved since radio waves travel at approximately 300 metres per microsecond (over 186,000 miles per second).

So far, we have been considering the determination of the position of an observer on the earth's surface and so in two dimensions. When the observer is in an aircraft the matter becomes a three-dimensional problem. For direction finding, this entails either the measurement of height of the aircraft by, for example, an altimeter, or the determination of the angle of elevation at which the radio waves travel between transmitter and receiver. The latter technique can now be used more effectively by making use of time or phase-difference measurements on waves received from two or more directions.

This paper deals with the general problem of position finding by radio. It is to be followed by two others which respectively describe the various techniques which have been developed as aids to marine navigation, and the special problems involved in connection with aeronautical navigation.

RADIO DIRECTION FINDING BY RECEPTION

The simplest form of radio direction finder comprises a plane vertical loop rotating about a vertical axis. If the loop is tuned to the desired frequency or wavelength and connected to a suitable receiver, the strength of the signal received will depend upon the direction of arrival of the radio waves relative to the plane of the loop. The signals will in fact be proportional to the cosine of the angle between the plane of the loop and the direction of the waves. Thus as the loop is rotated through 360° the signal passes through two positions of maximum and two of minimum—ideally zero—strength. This is represented by the well-known "figure of eight" diagram. The rate of change of signal strength with rotation is greatest at the minimum position so that in order to determine the bearing of a distant transmitting station, the loop is turned until the signal disappears. It is then known that the waves are arriving from a direction at right angles to the plane of the loop. By the addition of a short vertical aerial and suitable circuit arrangements this diagram can be transformed into the heartshape or cardioid, which eliminates the 180° uncertainty in the direction.

This is the basis of the simple rotating loop direction finder which has been in use for many years as an aid to marine navigation. The loop is usually mounted on the bridge or above the wheel-house, and it can be rotated by a simple hand-wheel by the navigator whenever a bearing is required for plotting in the chart-room. This marine direction finder is a simple, inexpensive and reliable instrument, While it can be used to take bearings on any transmitting stations in a known position, its application has been greatly enhanced by the installation throughout the world of a number of fixed beacon transmitters which emit special signals on a medium frequency in the region of 300 kc/s (wavelength 1,000 m). The ship's direction finder can also be used to take a bearing on the transmitter of another ship, a facility which has frequently proved useful in cases of distress.

In a similar manner, medium wave loop direction finders find a use in aircraft, but owing to the greater speed of travel it is more usual to have some automatic means of indicating the bearing of the distant sending station, even though this may to some extent lower the overall accuracy. Radio beacons are used by aircraft primarily for flying along a predetermined course or for homing purposes, so that the majority of air beacons are located inland at airports or on the principal air routes. Ships' radio beacons on the other hand are installed on the coast, for the mariner uses his direction finder mainly for making a landfall and fixing his position at distances up to about 80 km (50 miles) off shore.

In the case of both ship and aircraft installations it is necessary for the radio direction finder to be calibrated in order to ascertain, and if possible compensate for, the errors arising from the re-radiation of waves from metallic portions of the craft. It is also evident that the radio bearing is taken relatively to the craft itself and that in order to translate this into a true direction for plotting on a chart the direction in which the craft is heading must be observed independently, usually from a magnetic or gyro compass.

For the case of a direction finder installed on land a much larger loop aerial system is frequently used in order to obtain greater range. This usually comprises two fixed vertical loops with their planes at right angles to each other, and they are connected to the fixed field coils of an instrument known as a radiogoniometer, first described by E. Bellini and A. Tosi in 1907. The currents in these coils, corresponding to the signals induced in the two aerials by the arriving waves, reproduce in a small space a magnetic field of the same directional characteristic as the field in the arriving radio waves. Hence, by rotating a search coil inside the instrument, the direction of the waves can be observed in precisely the same manner as by using a rotating loop aerial.

In an alternative system the signals induced in the two aerials are applied to two identical receivers, the outputs of which are connected to the two pairs of deflecting plates of a cathode-ray tube. This combination is termed a cathode-ray direction finder, in which the bearing of the incoming signals is observed from the direction of the trace of the deflected spot of light on the

* Three papers read before Section G, British Association, in Glasgow, on Tuesday, 2 September, 1958.

fluorescent screen of the tube. This system was first developed by Sir Robert Watson-Watt and, with large fixed loops operating at the very low frequencies of 10 to 30 kc/s, was used for determining the direction of arrival of atmospherics, which are transient radio waves generated by lightning flashes. This instrument has since been developed to a very high degree and is used by meteorologists in various parts of the world. A network of four stations in this country is used for simultaneous daily observation of the directions of the arriving atmospherics. A plot of these directions shows the position of the main sources of atmospheric storm areas at distances up to some 3,000 km (2,000 miles) or more; and this information supplements other meteorological information for weather forecasting purposes.

IMPROVING ACCURACY

When a loop direction finder is used to take bearings on waves which are not travelling horizontally along the ground but arrive at an angle of elevation thereto, the instrument is subject to what is termed polarisation error on account of the fact that such downcoming waves are not entirely vertically polarised (electric force in a vertical plane) but contain a proportion of horizontally polarised (electric force horizontal) component. The resulting polarisation error can be reduced and even eliminated by the use of a special aerial system in which all the active members are vertical, and the horizontal connecting members are so arranged that all signal currents induced therein are self-compensating. We thus have the spaced vertical aerial system which was patented by F. Adcock in 1919 and which has been used extensively both as a rotating H-aerial and as a fixed aerial with a radiogoniometer. This system has indeed made possible the use of direction finding at long ranges where the propagation of short radio waves takes place by successive reflections from the ionosphere, so that the waves arrive at the receiver at an angle of elevation varying between 2° or 3° up to 30° or so to the horizontal. Just as with fixed loops, a pair of spaced vertical aerials can be combined with a cathode-ray tube receiver, and this type of direction finder has been very extensively used in recent years for taking bearings of ship, aircraft and ground transmitters at distances of many thousands of kilometres, under conditions in which the existence of polarisation error would have made the loop aerial system quite ineffective.

In spite of its high degree of development, however, this Adcock type of direction finder suffers from somewhat serious limitations under certain conditions of use. The first is that its polarisation is high when installed on sites of low electrical conductivity, although this can, to some extent, be mitigated by the use of a ground mat or earth screen laid over the ground below the aerial system. The second drawback is that it is unable on almost any site to give accurate bearings when receiving steeply incident waves from the ionosphere, or under conditions when two or more sets of waves or rays are being received from the ionosphere. These difficulties can be materially reduced by replacing each of the open vertical aerials by vertical closed loops to form what is termed a spaced-loop system, which is free from polarisation error because of the balanced nature of each of the loop aerials to its feeder. But it is less sensitive than the vertical aerial system and, moreover, can only be used in practice as a rotating aerial direction finder. In spite of this and certain other limitations, the spaced loop direction finder has proved a very useful tool in research work on wave propagation, and it is capable of a very high performance in studying the direction of waves travelling under varying conditions between the sending and receiving stations.

It must also be realised that the reflecting layers in the ionosphere are not always horizontal. They are subject to varying tilts of 1° or 2°, and reflection from such inclined regions can cause an appreciable deviation of the waves from the great circle plane between transmitter and receiver. Thus, while the direction finder as an instrument may give an accurate indication of the direction of arrival of the waves, this is not necessarily the true direction of the transmitting station, which is what is sought in practice.

WIDE-APERTURE TECHNIQUE

In the systems so far considered, the dimensions of the receiving aerial are usually a fraction of the length of the radio waves in use, and so only a small portion of the wavefront is being explored at the receiving site. This wavefront may be seriously distorted under conditions in which a single major ray, corresponding to the principal mode of propagation, has superimposed on it a number of secondary rays due to scattering of the primary radiation by re-radiating objects or irregularities in the medium of transmission. The arrival of two or more sets of waves from the ionosphere due to varying modes of transmission will also make it difficult, if not impossible, to deduce accurately the direction of the principal wave component in the received radiation from measurements made over a very small portion of the wavefront.

Investigations in recent years have shown that a more accurate determination of the true direction of arrival of the principal component of the received radiation can be obtained by examining a larger area of the wavefront by using a receiving aerial system having an aperture of several wavelengths. Such "wide aperture systems," as they are called, have been developed for use both in the high-frequency band (3 to 30 Mc/s) where long-distance transmission takes place by successive reflections between the ionosphere and the ground; and at the very high frequencies, above 30 Mc/s, where the receiving aerial is particularly subject to re-radiation from nearby objects, and where accurate bearing observation on steeply incident downcoming waves as, for example, from aircraft, is important in practice.

In a typical wide-aperture system a number of simple aerials are erected at uniform spacing round a circle of from one to a few wavelengths in diameter. By an electrical switching arrangement each aerial is connected in turn to the receiver and the phase of the current induced in it by the arriving waves is compared with that in a fixed reference aerial. The switching is carried out by a phase modulation of the received signals at a frequency of 50 cycles per second, which is high enough to render the system independent of fluctuations due to fading or other wave interference effects. The aerial system may be thought of as a pair of spaced vertical aerials, less than half a wavelength apart, rotating at the end of a horizontal arm set at right-angles to the plane containing them. The bearing of the incoming signals is displayed as a radial line on the screen of a cathode-ray tube indicator. It can be shown theoretically that this "commutated-aerial direction finder" with a diameter of one wavelength should be effective in reducing site-errors to about one-fifth of the value obtained with a narrow-aperture spaced vertical aerial instrument. A practical comparison between an Adcock direction finder and a c.a.d.f. system of one wavelength aperture showed that in the short wave band (frequencies between 8 and 12 Mc/s) the bearing fluctuations due to variations in the ionospheric rays were appreciably reduced. More practical experience is, however, required to check the theoretical predictions of the improved performance attainable by the use of wide-aperture direction finding systems, which are likely to find considerable application in connection with marine and aeronautical navigation.

RADIO DIRECTION FINDING BY TRANSMISSION

As an alternative to the use of a special radio receiving instrument for the determination of bearings, the directional property can be transferred to the sending station so that a bearing can be determined at a distant receiving station by the aid of some characteristic of the emitted radiation.

The Rotating Loop Beacon.—Prominent among the early practical systems capable of giving bearing information in all directions was the rotating loop beacon developed and used for some years in Great Britain. This was a simple inversion of the loop direction finder, and it provided a polar radiation diagram of the figure-of-eight pattern which rotated with the transmitting aerial at a speed of one revolution a minute. A special code-signal was emitted to indicate when the direction of zero or minimum radiation was due north or east; and an observer with an ordinary radio receiver obtained his bearing from an observation of the time taken for the signal to pass through a minimum intensity after hearing one or other of these code signals. Although the system was in operation in England particularly for the use of the mercantile marine for some fifteen years, it was not adopted on a wide scale. As it used a loop aerial, the system was subject to polarisation errors at ranges at which ionospheric rays were received; although proposals were made to extend the reliable bearing range by using a spaced vertical aerial system at the transmitter, no serious experiments were made to carry this into effect.

The Equi-Signal Radio Beacon.—Another system of defining a direction by a special type of emission is that of the equi-signal zone radio beacon which has been developed and used very extensively for the guidance of aircraft. In its original form this system emits two narrow overlapping beams of radiation, each of which is characterised by a simple morse signal. The two beams are switched on alternately and, along their line of intersection, the two signals are of equal strength and merge into a continuous dash. On either side of this line one of the signals is stronger than the other, and it is immediately evident to the observer, in an aircraft for example, in which direction he is to turn in order to get into the equi-signal zone. Although an aural indication of the signal is adequate and very useful, it is now usual for a simple indicator type of instrument to be provided in the craft. By keeping the pointer of such an instrument in the mid-position, the aircraft can be guided towards the beacon.

This system is particularly useful for defining long straight routes, or for assisting aircraft in "homing" on to their destination at which such a beacon is installed. Special arrangements of feeding the transmitting aerial systems through a goniometer have been developed, so that the course defined could be turned in any desired direction; installations defining simultaneously a number of courses have been applied to the problem of landing aircraft arriving from different directions.

The Consol System.—Another system which comes within the scope of direction finding by transmission is that known as Consol, which comprises a ground beacon station with three vertical aerials spaced in line at about 2·5 km (1·8 miles) apart and energised through transmission lines at a medium frequency between 260 and 500 kc/s (wavelength between 600 and 900 metres approximately). The system radiates a pattern of dot and dash signals in six sectors, and this pattern is rotated through an arc of 20° during a keying operation in which the phase of the currents fed to the outer aerials is altered uniformly in relation to the current in the centre aerial. An observer using an ordinary receiver will hear the signals change during the half-minute of operation from a succession of, say, dashes through an equal signal period to a succession of dots. The total number of characters heard is 60, and by counting the number of dots and dashes on either side of the continuous signal a position line can be determined. The coverage area comprises two sectors 120° wide centred on the line normal to the aerial system. By reference to a suitable chart it is possible to obtain an accurate bearing on one of six alternative position lines about 20° apart in each of the two sectors. Usually the observer will know his approximate position; if any ambiguity arises as to which of the position

lines is applicable, this can be resolved by taking an approximate bearing of the Consol station with an ordinary loop direction finder, and then determining the accurate value of the position line by the dot and dash counts. The observer can establish his position by reference to two independently operated Consol ground beacons. In this way the system provides reasonably accurate indications of position at distances up to about 2,500 km (1,500 miles) over the sea and 1,600 km (1,000 miles) over land.

As with other systems of direction finding the accuracy attainable is subject to limitations when the distance and other conditions are such that both ionospheric and ground rays are being received. The effect of such multiple path transmission is least along the line normal to the beacon aerial system and greatest along directions near the edge of the coverage area. The system has the same advantage as the rotating loop beacon in that no special equipment is needed by the observer on land or in a ship or aircraft, and no calibration of the receiving installation is involved.

RADAR TECHNIQUES

The introduction and development of radar technique has provided a means of measuring distance directly by observing the time taken for radio waves to travel between two points. The speed with which the waves travel is very high, being approximately 300 metres per microsecond or over 186,000 miles a second. In the basic use of radar, a transmitter emits pulses of radio waves from an aerial which concentrates the radiation in a particular direction. The waves reflected from various objects, which may be fixed or moving, along this direction, are observed on the cathode-ray tube of a receiver close to the transmitter. The time taken between the emission of each pulse and the return of its echo is measured and, from a knowledge of the speed of the waves, the distance of the reflecting object can be determined. Since the direction of transmission is also known, this procedure provides a means for the observer to determine his position relative to the points from which he is observing reflected waves.

This basic technique has been developed and elaborated in various ways for direct application to the navigation of ships and aircraft and also for land surveying requirements. In one development the transmitter and receiver are associated with a common aerial and reflector system which is continuously rotated in azimuth and also, if necessary, over a limited arc of elevation. In one type of display associated with the receiver a radial line on the screen of the cathode ray rotates continuously in synchronism with the rotating aerial system. As echo signals are received from the various reflecting objects, bright spots appear in the appropriate positions on the tube, which thus presents a panoramic display of the irregularities of the land with the hills, trees and buildings surrounding the observer. This " plan position indicator," as it is called, is most useful to ships and aircraft in identifying passage over towns or along a coastline and for clarifying the approach to an airfield or a harbour entrance. When applied in the reverse sense, with the installation and observer in a fixed position on land, it provides the airport or harbour controller with a display showing him the exact position of all aircraft or ships within his zone of control; since he can be in touch with these by radio communication the controller can assist the navigators towards their destination.

Several of these developments have been associated with the use of very short radio waves a few centimetres in length; and among other applications this has provided the land surveyor with the radio equivalent of his theodolite. By setting up a simple reflector at a known position, the land around it can be accurately surveyed with a portable tellurometer—as it is called. This is a combined transmitter and receiver of very short waves, with means for measuring the time of transit by the phase difference of the emitted waves and those returned from the reflector. In another application the speed of an aircraft can be determined by an observer in it. In this system, continuous waves are emitted and directed with a forward component towards the earth. Due to the motion of the aircraft relative to the ground, the apparent frequency of the reflected waves differs from that of the transmitter due to Doppler effects; by measuring this frequency shift the speed of the aircraft relative to the ground can be determined. In an earlier system the radiation was directed vertically downwards and its frequency varied cyclically. A comparison of the emitted and received frequencies provided a means of measuring the height of the aircraft above the terrain beneath.

Many ingenious variations of the essential principles of radar technique have been developed over the past twenty years or so, using either pulse or frequency modulation and observations of the time of arrival of echo signal reflected from objects in known positions to provide means for determining the position of the observer. The fact that reflections are usually obtained also from other craft either on sea or in the air is also valuable additional information which can be used either as an aid to navigation or as a means for taking appropriate action to avoid collisions. The meteorologist also uses radar for following the drift of free sounding balloons and so determining the speed and direction of the winds at various heights in the atmosphere.

HYPERBOLIC SYSTEMS

Following the appreciation and use of radar techniques as an aid to position finding and navigation there were developed a number of methods of determining position by radio waves, these methods being generally defined as hyperbolic systems on account of the fact that they make use of a reference system of hyperbolae. The various systems fall into two general classes depending upon the use of pulse modulated and continuous waves respectively. In the former class are two systems : the Gee system which was developed in the United Kingdom for aircraft navigation at distances up to some 300 miles, and Loran, developed in the United States of America, for the navigation of both ships and aircraft, at appreciably greater ranges.

Both these pulse-modulated systems depend upon the same fundamental principle of determining the difference in time of arrival of pulses of radio waves emitted simultaneously, or with a known delay, from two sending stations located on the ground at the ends of a suitable base-line. With a knowledge of the speed with which the waves travel the observer at the receiving station can then deduce the difference in his distance from the two transmitting stations. The locus of a point having a constant difference in distance from two fixed points is a hyperbola; and so the above measurement places the position of the observer on one of a series of confocal hyperbolae. If the measurement is repeated on the signals from one of the first pair of stations and on those from a third synchronised station, the position is found on one of a series of intersecting hyperbolae, and so a true fix is obtained.

The Gee system operates on frequencies between 20 and 80 Mc/s (wavelengths 3·75 to 15 metres) and relies upon direct-ray transmission to the point of reception. While it is sometimes used for short-range surface navigation, its specified field of application is for aircraft use. Loran operates on much longer waves in the frequency band 1,700 to 2,000 kc/s (wavelength 150 to 170 metres), and relies upon a much greater range of ground wave propagation. Depending upon the power provided at the transmitting stations, the reliable range over sea may be up to 1,200 km (750 miles) or so in the daytime, and rather less than half this for overland transmission. At night, the ground wave range is usually reduced by the increase in atmospheric noise at these low frequencies; On the other hand, ionospheric waves, which are almost completely absorbed by day, become effective at night and increase the reliable range to some 2,400 km (1,500 miles).

Turning to the other class, an alternative method of determining the difference in time of transit of waves from two sending stations to a single receiving station is based on the use of continuous, or modulated continuous waves, and the use of a known radio or audio frequency to make the time determination. In the Decca system, continuous waves are used, and by measuring the phase-difference between the waves received from two sending stations, maintained in exact synchronism, the difference in time of transmission and so of the path difference between the receiver and the two sending stations, can be measured to a very high order of accuracy. As in the case of the pulse-modulated methods described, each pair of stations gives rise to a series of confocal hyperbolae representing loci of equal phase-difference from the sending stations. This Decca system has been developed to a very high degree, and several chains of four synchronised stations are now in operation, for use at distances for which ground wave propagation prevails. Given a knowledge of the phase velocity of the waves over the various paths in use, the precision of indication can be quite high. It can be used for open-sea navigation at ranges of hundreds of kilometres, as well as at shorter distances for making a landfall or even negotiating a harbour entrance. While special receiving equipment is required for measuring the phase differences accurately, this has been developed to such a degree that automatic direct-reading meters are in use. The readings of these instruments can be directly transferred to special charts, so facilitating the plotting of position of the craft and the course it is following.

CONCLUSIONS

The object of this brief survey has been to describe the present state of the various techniques for determining a position on land, at sea or in the air by means of radio waves. Some of the systems are based on the use of the simplest possible apparatus by the observer, while others incorporate some of the most ingenious developments of electronic instruments. For navigational use, accuracy and reliability are of paramount importance; and hence it is necessary to take into account the vagaries of the radio waves themselves in traversing the path between sending and receiving stations. Our steadily increasing knowledge of the phenomena associated with the propagation of radio waves over land and sea and through the upper and lower atmosphere has been combined with advances in precise measuring technique to assist the development and progress of radio aids to navigation and surveying.

Although it has been possible in this review to refer to outstanding typical systems, the number of variations on these is very large at the present time. One of the problems which has confronted those in responsibility is to decide which one or more of the systems will serve the needs of air and marine navigators and also the land surveyor. In some quarters it may be claimed that one of the essentials of a navigational aid is that the receiving end should be simple, and that it should require little additional apparatus beyond what the navigator has for other radiocommunication purposes. It should also be possible for him to read directly from his indicating instrument his position or a figure which he can take straight to a chart on which his course can be plotted. Another matter which is of importance in connection with world-wide travel, whether by sea or air, is that there should be some measure of uniformity in the systems in use by different countries, so as to avoid the need for aircraft and ships to carry several sets of equipment in order to navigate from one port or aerodrome to another. But here I must leave the matter to allow my colleagues to describe to you some of the special problems associated with the navigation of ships and aircraft.

MARINE RADIO NAVIGATIONAL AIDS

By B. G. Pressey, PH.D., M.SC.(ENG.), M.I.E.E.*

THE mariner, unlike the airman, is in general an independent navigator in that he chooses his course and has to rely very largely upon his own observations in order to determine his position and aviod danger. Thus the two principal navigational questions to which he requires an answer are "where am I?" and "how near am I to danger?"

The answer to the first question has been, and still is, to a large extent, obtained by visual observations on the sun, stars or landmarks and by dead reckoning, that is, by the calculation of the change in position from the measured speed and direction. When the celestial marks are obscured and true speed and direction are difficult to estimate, radio can provide a valuable aid to position fixing. To answer the second question the mariner uses his eyes, but when visibility is poor he must heave to or turn to radio to supply him with "eyes" which are unaffected by such conditions.

DIRECTION FINDERS

Mention has already been made in the previous paper of the oldest type of radio aid, the direction finder. Its chief marine use is as a ship-borne instrument operating in conjunction with a world-wide network of medium frequency radio beacons. Bearings are taken on two or more of these beacon transmitters, lines representing the direction of the ship from the beacons are plotted on a chart, and the ship's position is given by the intersection of these lines. This system is still in common use by craft of all sizes and MTCA regulations require a direction finder to be fitted on all British passenger-carrying ships of over 5,000 tons.

A position-fixing service for ships is also provided by networks of land-based direction finders. There are about 20 such stations sited around the coasts of Great Britain and on request from a ship the appropriate stations take bearings on its signals, determine its position and transmit the information to the ship. Probably the most important use of this service is the location of vessels in distress and the guidance of the rescue craft.

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DIRECTIONAL BEACONS

Developments during the second world war have given the mariner three new radio aids: a long-range directional beacon, position-fixing systems of the hyperbolic type, and radar.

The first, known as Consol, was of German origin. As is described in the previous paper, the Consol transmitter radiates a coded signal consisting of 60 dots and dashes which vary in their arrangement according to the direction of the receiver. An observer using an ordinary receiver will hear first the call sign of the beacon, then a long dash and thirdly a series of dots or dashes which merge into a continuous note and then revert to a series of dashes or dots. By counting the number of dots or dashes which occur before the continuous note and referring to a special chart which is overprinted with correspondingly labelled radial lines, the navigator is able to determine his bearing from the beacon. There will be some ambiguity about this bearing as the same count may be obtained in each of 10 or 12 sectors, but usually the observer knows his approximate position and is able to select the correct sector. Alternatively, the ambiguity may be resolved by taking a bearing on the beacon during the period of the long dash provided for this purpose.

There are now five Consol beacons in operation which are so placed that by taking bearings on two of them a mariner may find his position over a wide area of the North Sea and parts of the North Atlantic. The position-fixing accuracy depends on the distance of the observer from the beacon, his position in the coverage area and the time of day; within a range of 1,000 nautical miles of the beacon it varies from a few miles to about 20 miles. This system is well suited to the use of small craft since the only requirement is a broadcast receiver and a Consol chart or tables. For this reason, it is extensively used by fishing vessels.

HYPERBOLIC POSITION-FIXING

The two-position fixing systems of the hyperbolic type which are in common use by mariners are the British Decca Navigator and the United States Loran system. The former is a continuous-wave system for medium-range operation and the latter a pulse system for longer range use; the principles of operation of both have been described in the previous paper.

The first Decca chain of transmitting stations was set up in the south-east of England to cover the Channel and the Thames estuary and its approaches. It consists of four stations: a central master station and three slave stations located approximately at the corners of an equilateral triangle. Each slave station and the master form a pair and with each of the three pairs is associated a hyperbolic pattern of position lines which is superimposed on standard charts, a different colour, red, green or purple being used for each pattern. A special receiver on board the ship receives the signals from all transmitters simultaneously and indicates on a meter, known as a Decometer, the difference in phase between the two signals from each pair

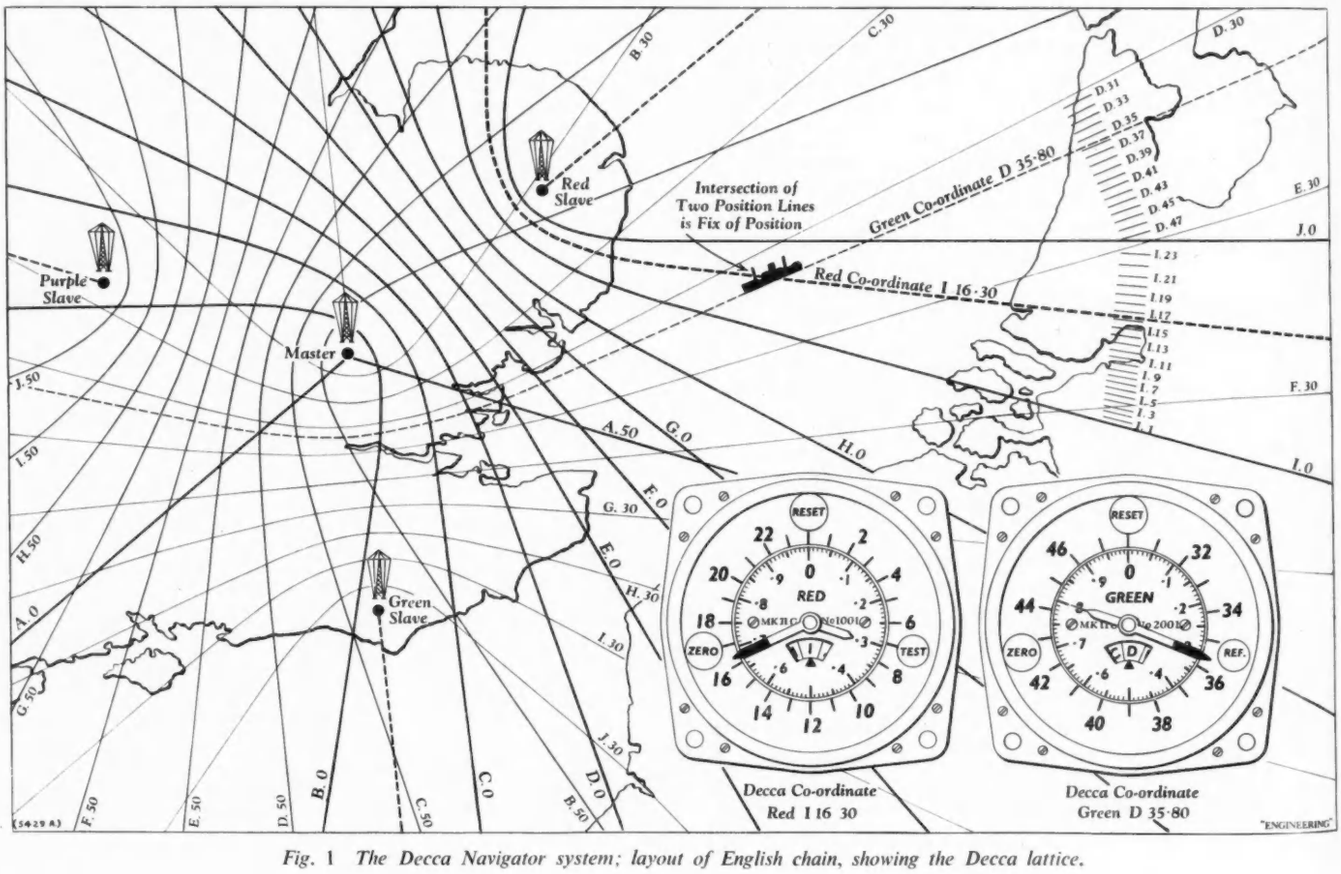


Fig. 1 The Decca Navigator system; layout of English chain, showing the Decca lattice.

of stations. There are three meters, one for each pattern, and their indication is in terms of "lanes"—one lane is the spacing between two adjacent hyperbolae corresponding to zero phase difference. In the example shown in Fig. 1, the navigator on the ship would read 16·3 on the red pattern meter and 35·8 on the green pattern meter and the intersection of the correspondingly marked position lines on his chart would give his position.

Although the decometers show a whole number of lanes, as well as fractions of a lane, the whole number cannot be relied upon unless the decometer pointers have been correctly set at a time when the ship's position is known to within half a lane. This setting procedure may be conveniently done as the ship leaves port, but when coming into the coverage area of the system other means of identifying the correct lane are required. For this purpose a lane-identification system is incorporated in the chain. It provides coarse hyperbolic patterns in which each lane embraces a number of lanes of the normal pattern, 18 in the case of the green pattern, and 24 and 30 in the cases of the red and purple patterns, respectively. A fourth decometer indicates the correct whole lane for each pattern in succession once every minute.

Decca chains now cover the whole of the British Isles and a large part of Western European waters; there are also four chains in operation in eastern Canada. The position-fixing accuracy of the system varies from a few tens of yards in areas where the geometry of the patterns is favourable to a few miles at night at the nominal 240 nautical mile limit of range from the master station.

Loran, which is essentially a long-range system, utilises pulse-modulated signals radiated from pairs of stations spaced 300 to 600 nautical miles apart. The difference in the times of arrival of the pulses from the two stations of a pair are measured on a cathode-ray tube and the corresponding hyperbolic position line found by reference to a special chart in a manner similar to that used with the Decca Navigator. Over sea the service range extends to about 700 miles in the daytime and, because of the better propagation conditions, to about 1,500 miles at night. Position fixing accuracy is high, being about 0·5 per cent of the range, i.e., 5 nautical miles at 1,000 miles. Its chains cover the North Atlantic, North and Central America, and northern parts of the Pacific.

SHIP-BORNE RADAR

Marine radar equipments use radio waves in the microwave band, i.e., with wavelengths of only a few centimetres, which is at the opposite end of the frequency spectrum to the low and medium-frequency bands used by the aids already mentioned. The equipment consists of four principal parts, an aerial, or scanner, a transmitter, a receiver and a display unit. The scanner, mounted on a high point of the ship's superstructure or on a mast, rotates about a vertical axis and scans the sea with a narrow radio beam much in the same manner as does a lighthouse. Objects in the path of this beam reflect the radio waves back to the scanner which passes them on to the receiver and the display unit. The usual type of display is that already referred to as a plan position indicator and consists of a cathode-ray tube of about 12 in diameter on which the radio echoes from coastlines, hills, ships, buoys, etc., appear as bright spots outlining these objects. The navigator thus obtains a map-like picture of his surroundings, of the form shown in Fig. 2. The range covered by the display may be varied from about ½ up to 30 nautical miles, which is the normal effective range of the present marine radars. The maximum distance at which objects can be detected on the screen varies according to their nature and size and with the height of the scanner above sea level. For example, with a scanner height of 50 ft cliffs which are 200 ft high can usually be seen at about 20 miles, a 10,000 ton ship at 10 miles, a buoy at two or three miles. This range may be reduced by heavy rain but is unaffected by fog.

Fig. 2 Radar screen picture on a ship off Cowes, Isle of Wight. The ship's position is at the centre of the picture and the radial line shows that it is heading in towards Portsmouth. The entrance to Southampton Water is shown to the north. Only a small part of the Isle of Wight around Cowes is seen because the remainder of the island within range is screened from the radar beam.

Interpretation of the picture is aided by the superposition on the screen of electronically-produced reference lines. A radial line indicates the ship's heading and concentric circles spaced at known intervals provide range markers. Accurate range measurement may be made by means of a variable range circle, the radius of which is adjusted by a dial calibrated in nautical miles. Bearing determinations are obtained by means of a cursor line engraved on a rotatable Perspex cover and a protractor scale around the periphery of the screen.

The type of display described above, in which the ship's position is at the centre of the screen, was, until recently, the one universally used. If the ship is moving the echoes of all objects, whether stationary or moving, traverse the screen at a speed and in a direction relative to those of the ship. In a busy shipping lane it is difficult to follow readily the movement of other ships and to distinguish them from stationary objects. A recent development, known as a true-motion display, overcomes this difficulty. The centre of the trace is caused to move across the screen in the direction of the ship's course and at a speed related to that of the ship. As a result, stationary objects remain in fixed positions and echoes of moving objects traverse the screen along their true courses.

Ship-borne radar has two main uses: as an aid to position fixing in coastal waters and as a warning of danger. Position location is carried out by measuring on the display, using the electronic aids provided, the distances and bearings of recognisable landmarks and plotting on a chart. In order to aid the identification of certain marks, such as a light vessel which would otherwise be difficult to identify among other shipping, radar beacons have been developed. These beacons transmit on frequencies within the radar band and produce on the display a broad line which extends radially from the echo being identified towards the edge of the picture.

The more important use of radar, however, is in the prevention of collision and in the navigation of narrow waterways in thick weather. For the former purpose the true-motion display described above is of great assistance since a moving vessel may be readily distinguished and its course and nearness of approach more easily estimated than with the relative-motion display. Although the echoes from the buoys which mark a navigational channel may be seen on the radar screen they may not be readily distinguished from other echoes. To make the position of the

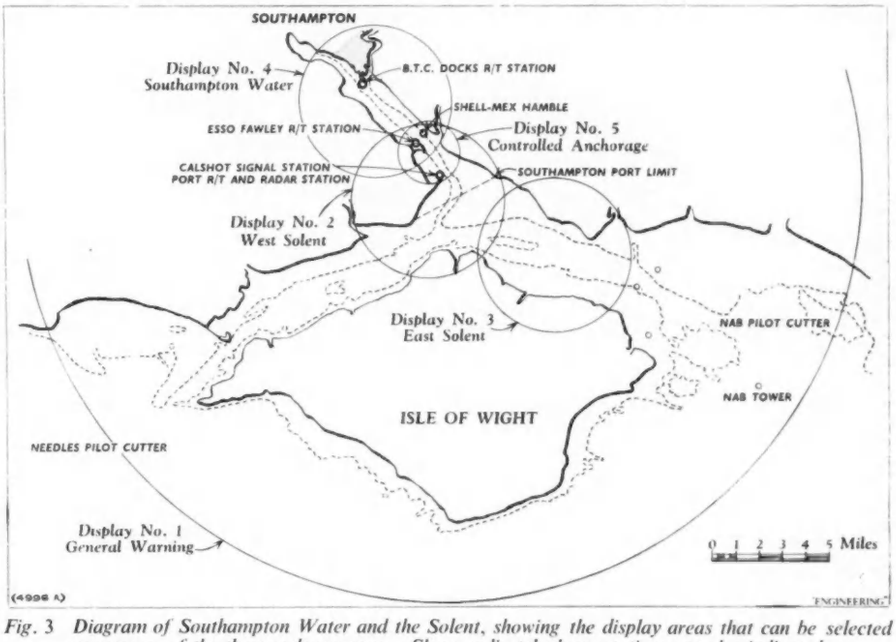


Fig. 3 Diagram of Southampton Water and the Solent, showing the display areas that can be selected on any one of the three radar screens. Shore radio telephony stations are also indicated.

channel clearer radar reflectors are often mounted on these buoys so as to enhance their echoes.

While considering navigation in narrow waterways mention should be made of the recent development of a microwave course beacon which enables ships having the appropriate receiver to follow a straight line track through a harbour approach. The beacon transmits a split beam, one half of which is keyed with the morse letter B (— · · ·) and the other with the letter V (· · · —). The centre line of the beam is directed along the track which is to be followed by the ship. If the ship is at one side of the track the keyed signal is distinctly heard; the one letter if the ship is to starboard of the track and the other letter if it is to port. When exactly on track no keying is heard, only a continuous note.

The receiver for this equipment is a small portable instrument which can be held in the hand and operates at ranges up to 7 nautical miles from the beacon. A device such as this is of particular value to small fishing craft using harbours where incidence of fog is high and

where the approach channels are comparatively easy to negotiate.

SURVEILLANCE RADAR

At a number of ports where the approach channel is lengthy and winding it is important for the master of a large vessel to have all necessary information as to the state of the channel before committing his ship to it. Often the presence of buildings or spits of land prevent the ship's radar from seeing right into the harbour, so that a land-based radar is better placed to give the mariner information.

Liverpool, in 1948, was the first port to fit a specially designed harbour surveillance radar. A more advanced model has recently been fitted at Southampton* and installations are also gaining in popularity in Europe. One interesting system is that covering the 20 mile length of the New Waterway from The Hook to Rotterdam. This has seven radar stations and has been in operation since 1956.

The Southampton installation, the location of which is shown in Fig. 3, has a 25 ft aperture aerial which is situated in a commanding position on the signal tower at Calshot. This aerial system is about five times larger than a ship-borne one and for this and other reasons enables a more detailed picture to be obtained It has three large-scale displays of 16 in diameter which together cover the area from Spithead in the East Solent to Gurnard Head in the West Solent and to King George V Graving Dock at the top of Southampton Water In addition each display is capable of being switched to a large-scale picture of the Fawley anchorage and also to a normal planned position indicator (p.p.i.) picture of 18 miles radius which includes the Nab Tower and the Needles. By means of electronic markers on the displays the distance and bearing of a ship from a navigational mark can be rapidly determined. The harbour authority can therefore provide information of a ship's position and its course and can also regulate the movement of shipping in the channel.

*See ENGRG, vol. 185, p.156 (31 Jan., 1958).

With the present systems of surveillance radar the information on the conditions in the channel is passed to the ship over a v.h.f. radio telephone. Such an arrangement has the disadvantage that only a limited number of ships can be dealt with at once and methods of transmitting the shore radar picture itself are being developed. In one such system the radar display is televised, transmitted to the ship and shown on a conventional television receiver. A system of this type is complex and costly and a more economically attractive one is that in which the raw radar information, i.e. the signals fed to the display, is transmitted. This is received in the ship and used to drive the ship's own radar display. The navigator is thus able to switch the picture on his display from that seen by his own radar to that seen by the shore-based one.

One important problem which arises in the operation of surveillance radars is that of positive identification of an echo with the particular ship with which the shore station is communicating. Each ship is shown on the display as a spot which cannot readily be identified even if the approximate position and course of the ship in question is known. One technique being tried to overcome this difficulty is that of providing the pilot with a small transponder beacon which he carries aboard the ship he is bringing into port. If this beacon is switched on at the request of the shore station there appears on the surveillance radar screen a radial line having in it a short break which occurs at the echo representing the ship to be identified.

CONCLUSIONS

In this paper an attempt has been made to describe the various radio navigational aids which are at present available to the mariner. Many are, of course, not exclusive to marine navigation. Some of them, such as Consol, Decca Navigator and Loran are used by both ships and aircraft, though the methods of displaying the information at the receiver may differ in the two cases. Other systems such as radar, both mobile and surveillance, and track beacons have their counterparts in the aeronautical field. Further details of the applications to air navigation will be given in the next paper.

Some indication of future developments has already been given. In the radar field these seem to be directed mainly towards obtaining the maximum amount of information from the aid by the improvement of the display and by the addition of auxiliary aids such as beacons and echo identification systems. The requirement for greater precision in the measurement of movement is likely to continue and consideration is being given to providing on the radar screen an indication, not only of the ship's position, but also of its size, aspect and direction of motion. This may involve the use of even higher radio frequencies in order to obtain the necessary discrimination, although the designer will be faced with the attendant disadvantage of greater range reduction by water-laden atmosphere.

Although position-fixing systems such as Consol, Decca Navigator and Loran have been in operation for a decade or more, studies of their performance are still being carried out with a view to improving accuracy and reliability. A new transmission technique now being tested on the English Decca chain will, it is predicted, considerably improve the reliability of lane-identification at the edge of the service area. Some thought is also being given to the development of very long range systems which would be suitable for world-wide coverage. Such systems would use very low frequency waves in the region of 10 to 14 kc/s (wavelengths of 30 to 21 km) and investigations are in progress to determine the propagational characteristics of such waves.

Acknowledgment is made to the Decca Navigator Company Limited and the Ministry of Transport and Civil Aviation for the provision of Figs. 1 and 2.

Further information on many of the radio aids may be obtained from the Proceedings of the Institution of Electrical Engineers, Convention on Radio Aids to Aeronautical and Marine Navigation, March 1958.

RADIO AIDS AND AERONAUTICAL NAVIGATION

By Caradoc Williams, B.SC., M.I.E.E.*

AERONAUTICAL navigation is the planning and control of the movement of aircraft in position and time along defined tracks so as to reach a prescribed destination in safety. Radio navigation aids play a vital part in the safe movement of aircraft. Problems which are peculiar to aeronautical navigation are present because aircraft move at high speed in three dimensions in a medium of low density.

The requirements of aeronautical radio navigation can be conveniently grouped into three classes:—

(1) Long-range navigation beyond about 250 miles, when radio signals propagated by reflection from the ionosphere may be used.

(2) Short-range navigation up to about 250 miles, when direct wave propagated signals may be used in the metric or centimetric wavebands.

(3) Very short-range precision navigation such as are required for the guidance of aircraft on to an airfield runway, when metric or centrimetric wavelength signals may be used.

TECHNIQUES OF RADIO NAVIGATION

A long established method of aeronautical navigation is by dead reckoning in which the direction of movement and speed of the aircraft are used to deduce its position relative to the starting point. An alternative method is to locate the aircraft by measurements within a fixed co-ordinate framework defined by radio techniques, as for example a bearing-distance lattice or a hyperbolic lattice as shown in Fig. 1.

Dead reckoning navigation is a process in which a position is determined by integrating the components of velocity of the aircraft along the axes of the latitude-longitude grid. The direction of motion of the aircraft is measured by the magnetic compass and the velocity by the airspeed indicator, but to this information must be added the wind direction and velocity components to deduce the true position of the aircraft relative to the ground. When this data is integrated over a long period, these dead reckoning processes can introduce large errors in the estimated position of the aircraft, due to inaccurate direction indications of the magnetic compass, the inability to make accurate measurements of airspeed above about 400 knots, and the unpredictable nature of the wind direction and speed, particularly at high altitudes. These errors in the knowledge of airspeed and wind have stimulated the development of the airborne Doppler system of radio navigation which measures accurately the ground speed and the drift of the aircraft, thus enabling an accurate computation of movement to be provided.

A form of aeronautical radio navigation in extensive use is the airborne direction finder called the Automatic Radio Compass, which provides the pilot with bearings or homing information with respect to simple low-power ground transmitting beacons or to broadcast stations. A typical radio compass equipment is shown in Fig. 2. It comprises a small iron-cored loop aerial contained in a streamlined casing mounted on the aircraft, a receiver incorporating a servo-mechanism to orient the loop automatically and one or more instruments in the aircraft to indicate bearing. By present needs, the aircraft radio compass is a rather inaccurate device because of the small physical size of the direction-finding loop aerial and the difficulty of locating the loop aerial on the aircraft fuselage. Furthermore, large errors can occur at night resulting from signals reflected by the ionosphere which are not plane polarised. Alternatively, these Direction Finder Stations may be located on the ground to measure the bearings from the V.H.F. (Very High Frequency) aircraft communication transmissions. Larger aerials can then be used and the direction finders located on sites selected for their relative freedom from bearing errors. The navigational information is communicated back to the aircraft on the radio communication channel.

This V.H.F. ground-based direction finder service is of vital importance for air-traffic control purposes, because, with the aid of ground-based radar stations, aircraft which do not carry radio aids other than the normal V.H.F. voice communication equipment can be located and identified by an air-traffic controller located on the ground. A disadvantage of the ground-based direction finder service is that it can handle only one aircraft transmission at one time and in an area of considerable air-traffic movement this leads to serious congestion of the service. The

* Radio Department, Royal Aircraft Establishment, Farnborough.

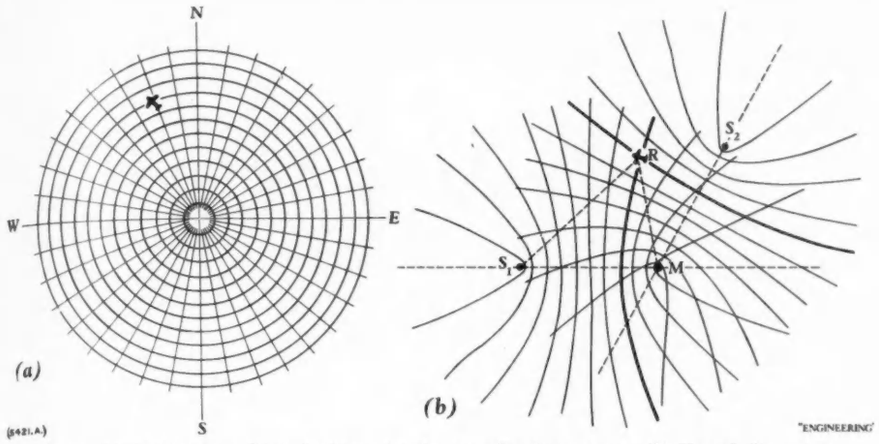


Fig. 1 Navigation co-ordinate lattices: (a) Distance-bearing system: (b) Hyperbolic system.

practice of turning a direction finder aerial by hand to obtain a bearing is too slow for aircraft moving at high speed and the immediate presentation of bearings has now been achieved by the V.H.F. Cathode-Ray Direction Finder[1], which shows instantaneously the bearings of aircraft as radial traces on the face of a cathode-ray tube. An example of this is the Cathode-Ray Direction Finder shown in Fig. 3; the C.R.D.F. uses five vertical aerials to give it directional properties. The small size of this aerial system restricts the accuracy to a few degrees of bearing, but a new technique, known as the Commutated Aerial Direction Finder has been developed[2]. This uses a large number of aerial elements in a circular disposition with a diameter of several wavelengths to improve the accuracy.

Direction finders are used to provide homing information or as part of an aircraft position fixing network. For the position fixing network the direction finding stations are widely separated to give good accuracy of fixing aircraft positions, and the D.F. bearings are passed automatically over land lines or radio links to a central control room where they are projected as images from small cathode-ray tubes on to the back of a translucent map, as illustrated in Fig. 4.

The air pilot flying in high density traffic areas requires immediate and accurate information of his position continuously indicated on instruments in the aircraft cockpit. This information can be provided by various kinds of ground-based navigational beacons which will be considered later in this paper (" Short-Range Navigation ").

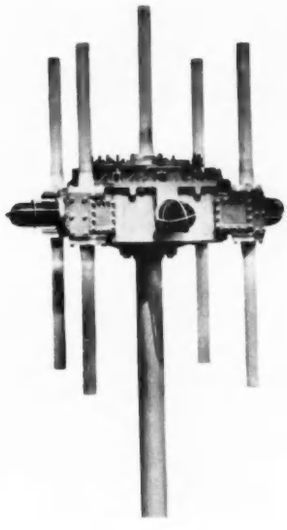
Fig. 2 Aircraft automatic radio compass.

SELF-CONTAINED NAVIGATION AIDS

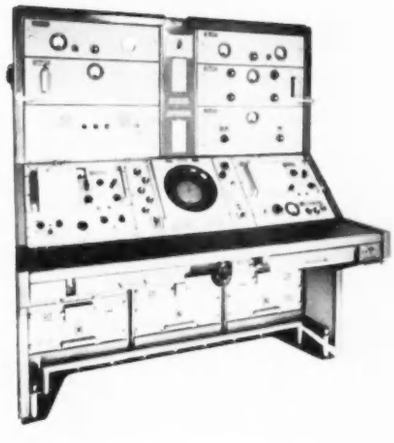
In regions of the world where there is a high density of air traffic, there is a need for distance bearing beacons or hyperbolic navigation systems which define an accurate lattice of co-ordinates within which all the aircraft move. However, these techniques necessitate the setting up of ground-based radio stations in many of the undeveloped parts of the world. This is often uneconomic or impracticable. In these areas it is preferable to use methods of navigation which although less accurate are self-contained within the aircraft, and do not require any ground-based radio stations for their functioning.

The Doppler system of radio navigation[3] is self-contained within the aircraft and uses the well-known effect of the apparent change of frequency which occurs when a signal source is approaching or receding from the observer. A

(a) R.D.F. station.



(b) Aerial system.



(c) Receiver.

Fig. 3 Cathode-ray direction finder (C.R.D.F.)

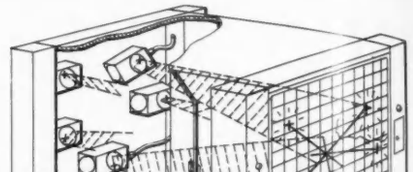


Fig. 4 Cathode-Ray Fixer Display from projection tubes. (Left) The display and (right) a representation of the apparatus.

common acoustic example of this effect is that of a train whistle: its sound rises in pitch as the train approaches an observer and drops in pitch as it recedes. The change of frequency of the note is directly proportional to the speed of the train.

In a similar manner a radio signal undergoes an apparent change of frequency when it is picked up by a radio receiver which is moving relative to the transmitting source. As the change of radio frequency is proportional to the relative velocity it is possible by this means to measure the speed of an aircraft in flight. A narrow beam radio signal radiated from the aircraft is directed toward the ground where it is reflected in various directions. Some of the energy is reflected back to the aircraft Doppler receiver where it is compared in frequency with the outgoing signal. A practical method of measuring the Doppler shift of radio frequency of an aircraft in flight is to use two narrow beams, as shown in Fig. 5(*a*), one beam being directed forward and downward and a second beam backward and downward relative to the aircraft axis. These two signals are reflected by the ground and received in the aircraft. The difference in frequency between the received signals is the Doppler frequency, which is directly proportional to the speed of the aircraft relative to the ground. By measurement of this Doppler frequency the ground speed can be indicated to the pilot on a meter calibrated in knots. In a practical example, if the beams are deflected downwards at 60° relative to the aircraft axis and the frequency of the radio transmissions is 9,000 Mc/s, the Doppler frequency for an aircraft flying at a speed of 300 knots is approximately 9 kc/s.

To deduce the position of an aircraft, both its speed and direction of movement must be known. The aircraft compass shows the direction in which the aircraft is pointing, but its direction of movement will differ from this according to the strength of cross-wind which causes the aircraft to drift from its intended path. The method of correcting for a cross-wind is to turn the aircraft toward the wind so as to give it a transverse velocity which compensates exactly for the drift. This angular change is known as the drift angle. In the past, an air navigator had no direct means of deducing the drift angle and had to rely upon rather inadequate meteorological information, but the Doppler navigation equipment gives him this information continuously as it can measure both the forward and transverse velocities.

To do this, a more complex aerial is used which radiates four beams as shown in Fig. 5(*b*). The whole aerial unit radiating these beams can be rotated horizontally relative to the aircraft axis and each diagonally opposite pair of beams is used to derive a Doppler frequency. When the two Doppler frequencies are equal the axis of the aerial unit is pointing in the direction of true movement of the aircraft and the drift angle is the angular difference between the axis of the aerial unit and that of the aircraft. The distance flown, ground speed and drift angle are shown on instruments and the navigator uses these data to plot his position. Alternatively, this information is fed into a computer which automatically shows the position of the aircraft in latitude and longitude or the distance flown and the deviations from an intended track. Typical Doppler radio navigation aircraft equipment is shown in Fig. 6. Distance accuracy is obtained to within about 0·2 per cent of the distance flown and the drift angle is measured to within about 0·2°. However, as the system is dependent on the aircraft magnetic compass, the overall accuracy is of the order of 1·0 per cent of the distance flown.

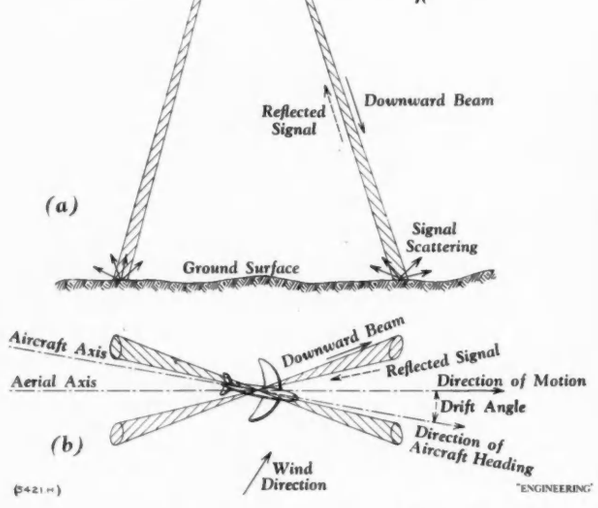


Fig. 5 Doppler navigation: (a) Side elevation of aircraft and beam radiation. (b) Plan of aircraft and beam radiation.

LONG RANGE NAVIGATION

For long-range radio navigation, low-frequency continuous wave or pulse-modulated signals may be used. These are usually radiated from widely separated radio transmitting stations in which the transmissions are synchronised in time to define a hyperbolic co-ordinate system. For example, in Fig. 1 (*b*) M is called the master station and S_1 is a slave station radiating pulses synchronised with the master. The relative times of arrival of the pulses at the aircraft receiver are dependent upon the difference in the path distances, MR − S_1R. The lines of constant time difference are hyperbolic in shape. By receiving signals from three stations, two hyperbolic position lines are obtained which intersect one another, the location of the aircraft being at the intersection shown at R. Groups of three or more stations operating together form a chain.

There are many systems of hyperbolic navigation in use, some of which use pulse modulation, the position lines being measured by the time separation of the pulses and others which radiate continuous wave signals, the position lines being measured by the phase difference of the signals from the master and slave stations. The mode of propagation is preferably by signals which are transmitted over the ground, but other modes of propagation such as single or multiple reflections from the ionosphere can be used, provided that the wave path is predictable and that corrections can be applied to the observations to deduce the over-ground distance. The high-frequency band is not much used for radio navigation beyond the range of the ground wave, because with modes of propagation which use waves reflected from the upper regions of the ionosphere the wave path is insufficiently predictable for navigational purposes. On the other hand, the use of low and very low frequencies is more practicable, because these signals are reflected by the much lower E-layer of the ionosphere and the wave path between the transmitters and receiver can be predicted with a reasonable degree of accuracy. The use of ionosphere-reflected waves for navigation is far less reliable than ground waves and considerably less accuracy is realised in consequence.

For aeronautical navigation, Gee, Loran and Consol are extensively used. Gee and Loran[4, 5], are pulse hyperbolic systems which were developed for military purposes during the war.

Fig. 6 Doppler Navigation Aircraft Equipment.

Consol[6] was derived from the German *Sonne* system and has the characteristic that bearings of Consol stations can be obtained in aircraft by the simple process of counting dot and dash characters received on a simple medium-frequency communications receiver. The process of deriving a position is rather slow and is therefore hardly acceptable for the navigation of high-speed aircraft.

A notable United Kingdom development which is undergoing experimental trials for air navigation across the North Atlantic is Dectra,[7] which is a low-frequency navigational co-ordinate system for use over busy long-distance air routes. As it is a technique which might be used extensively in the future for long-distance aeronautical navigation, it will be reviewed.

Dectra is a system primarily designed to provide track and position along a number of airways which may be 2,000 miles or more in length. It makes use of both ground- and ionosphere-reflected signals, depending upon the distance of the aircraft from the ground transmitting stations, and it supplements the existing medium-range Decca Navigator, which is only effective within the range of the ground-propagated wave, that is, about 250 miles.

Fig. 7 shows pairs of master and slave stations positioned at each end of the air route across the North Atlantic. These pairs of stations define hyperbolic position lines as lines of constant phase along the route for tracking purposes. The pairs of stations at each end of the route operate separately, except that the frequencies are interrelated to derive distance information along the tracks. Each pair of stations operates in the 70 kc/s band, the signals being switched from master to slave in time sequence. In the

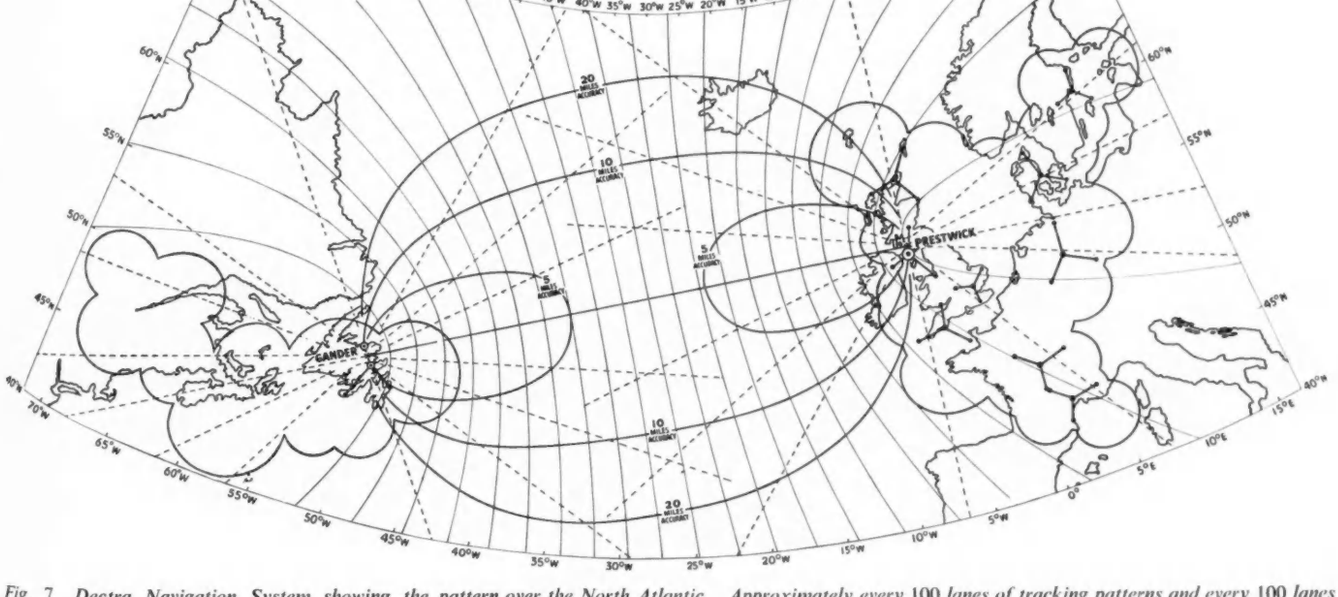


Fig. 7 Dectra Navigation System showing the pattern over the North Atlantic. Approximately every 100 *lanes of tracking patterns and every* 100 *lanes of ranging patterns are shown.*

aircraft receiver, a local oscillator is held in phase with the master signal, and this acts as a phase memory reference of the master signal when the slave station is radiating. The station pair nearest to the aircraft define a hyperbolic phase pattern which gives guidance to the aircraft in track until it reaches the mid-point of the route; the receiver channel is then changed to receive the master and slave stations at the other end of the route.

The frequencies at each end of the route are interrelated so as to defines a further hyperbolic pattern, which gives distance intercepts along the tracking lines. For this purpose signals must be received from each end of the route at the same time, their relative phase being measured to show movement along the tracking lines. The position of the aircraft is indicated automatically on a map which is located in the aircraft cockpit, the Dectra signals being used to operate a pen which moves over a roller-blind chart as shown in Fig. 8. The signals reach the receiver by either the direct wave or multiple reflections from the ionosphere. With ionosphere reflections the errors are dependent upon the obliquity of the transmission paths and the number of reflections. Accuracy of the order of 5 miles along the route can be achieved with the system.

Fig. 8 Decca Navigation Flight Log.

SHORT-RANGE NAVIGATION

The radio services formerly used for aeronautical navigation were direction-finding and two-or four-course track guides. These track guides were radio beams along which the pilot was able to fly the aircraft by listening to morse signals that converged into a steady tone when the aircraft was located on the beam. The track guides imposed inconvenient restrictions on flying in areas of high traffic density because the air space available was not fully used. Also, with the increase in aircraft speed, there was need for a simple and instantaneous indication of position which could be easily integrated with that provided by the other flying instruments in the aircraft cockpit. As a result of this need the V.H.F. Omnidirectional Range (V.O.R.) and Tacan systems emerged, as also did the Decca Navigator with the addition of the Flight Log for aeronautical use.

The V.O.R. ground beacon is a single-sited equipment operating at a fixed frequency in the 100 Mc/s frequency band which gives the bearing of the beacon to the air pilot. The range attainable depends upon the height of the aircraft. The beacon radiates two modulations on the same radio frequency carrier, one being a reference signal of fixed phase and the other having a phase delay which conveys the bearing information as the phase difference between the two modulations. Thus, by measurement of the relative phase of the two signals in the aircraft, the bearing of the aircraft relative to the beacon is indicated. Bearing information is given visually on a bearing indicator to within 5° and the pilot is able, by means of a bearing selector and a left-right needle indicator, to select and fly along any line which he chooses, radial to the beacon.

To provide a complete distance-bearing radio navigation service a separate pulse system called D.M.E. (Distance Measuring Equipment) is used to measure distance along the V.O.R. radials. This service is provided by a transmitter-receiver in the aircraft radiating pulses which are received by a ground beacon, the pulses being transmitted back to the aircraft on another frequency. The total time for the pulses to be propagated along the go and return path is related to the distance of the aircraft from the beacon and the information is presented to the pilot on a meter indicator.

The latest navigation system provides the bearing and distance services together, using a single airborne equipment called Tacan[8] which operates in the 1,000 Mc/s band. Each aircraft carries a transmitter that radiates pulses at a fixed recurrence rate which are received on a ground beacon where they are transmitted back to the aircraft on another frequency, the time pulses take to traverse the go and return path being related to the distance between the aircraft and the beacon.

At the ground beacon the returning pulses are amplitude modulated with the bearing information before they are transmitted back to the aircraft. The beacon is able to reply to about 100 aircraft at a time and, as would be expected, all these pulse replies are mixed together, but those intended for a particular aircraft are identified from all the others because they are phase coherent with respect to the regular outgoing pulses. All the beacon reply pulses are used together to carry the bearing information by modulating their level sinusoidally, this being achieved by a special form of continuously rotating aerial, the speed of rotation defining the modulation frequency, and phase of the modulation defining the bearing angle. With this system distance can be measured to an accuracy of about a quarter of a mile and bearing to 1½°, the information is shown to the pilot on a meter instrument with a dial having a circular bearing scale and an aperture in which the distance of the aircraft from the beacon is indicated, Fig. 9.

VERY SHORT-RANGE PRECISION NAVIGATION AIDS

Some kinds of navigation require great precision over a very limited area of coverage, for example during the landing of an aircraft in bad visibility. These aircraft movements create hazards where danger is imminent and immediate and accurate information must be provided. For this purpose high discrimination radars are located on airfields to give guidance to aircraft in a system called Precision Approach Radar (P.A.R.)[9] which enables aircraft to land under bad visibility conditions by means of directional and descent instructions given by the airfield controller to the pilot on the radio communication channel, illustrated in Fig. 10. The P.A.R. has separate radar aerials which radiate very narrow scanning beams in both the horizontal and vertical planes, and cathode-ray displays give the ground controller the distance of the aircraft, its direction, and angle of descent to the airfield runway. P.A.R. operates in the 3 cm band and gives a discrimination of the aircraft to about 20 ft at three-quarters of a mile from the touchdown point relative to the correct approach path. By using a pulse length of 0·2 microsec, discrimination in range to about 100 yd is attainable. When the aircraft is at three-quarters of a mile from touchdown, the high-intensity airfield landing lights on the approach to the runway will be visible and the pilot will complete the landing from his own observations.

Fig. 9 Tacan Distance-Bearing Indicator.

An alternative system of guidance to the airfield gives the pilot his directional information to the airfield by the Instrument Landing System (I.L.S.)[10], as depicted in Fig. 11. Two radio beams are used on the ground to indicate the correct path to the airfield, one being aligned to define the directional approach to the runway, and the other to define the angle of descent to the runway. The normal form of indication to the pilot is on a dial instrument in which two separate needles are located mutually at right-angles, one deflecting right and left of a vertical centre line defines the directional approach and the other deflecting up and down relative to a horizontal centre line defines the descent angle to the airfield runway.

This kind of information shows the pilot his displacement relative to the correct approach path, but in a fast-moving aircraft it is necessary for the pilot to know not only where he is, but what actions are necessary to restore the aircraft when it deviates from the correct approach path. This is made possible by feeding the indicator with information which virtually anticipates the future position of the aircraft and so enables the pilot to initiate a smooth recovery to the correct path. This information makes it very much easier for the pilot to fly along the beam, because at all times his objective is to fly so that the approach indicator needles show a zero deflection.

With large aircraft, the path of the aircraft to the airfield may be controlled by an automatic pilot which uses the incoming radio signals for guidance down the beam. The human pilot observes the progress of the landing approach by means of the aircraft flight instruments and does not exercise physical control over the path of the aircraft unless his judgment indicates that something is amiss in the automatic procedure. When the descent has reached a point where the pilot has direct vision of the runway lighting he releases the automatic pilot and exercises direct control to bring the aircraft to touch-down and finally to rest on the airfield runway.

Under conditions of bad visibility this last phase is still exceedingly difficult for the pilot to complete, particularly in some military machines where the design characteristics unavoidably restrict the pilot's downward vision from the cockpit—a facility which is essential during landing. To aid the pilot still further at this stage, methods are being developed using a magnetic field guidance cable on the ground for directional guidance and a very low-reading radio altimeter in the aircraft for descent guidance which will, through the automatic pilot, control the aircraft movements until it is at rest on the runway.

The need for complete reliability of all aspects of the control equipment at this crucial stage is so important as to present a paramount technical problem to its realisation.

CONCLUSIONS

Special problems arise in aeronautical navigation, because it involves the rapid movement of aircraft in three dimensions. The large increase in the volume of air traffic and the higher speed of aircraft movement during recent years have necessitated the development of more accurate navigational systems to ensure safety in flight, particularly under adverse weather conditions. Long-range, short-range, and very short-range precision navigation aspects for aircraft have been considered and some typical aircraft radio navigational techniques of more recent origin have been reviewed. The author considers that there is still further scope for original contribution in the field of radio aids to aeronautical navigation, as for example by the provision of a relatively simple aircraft separation monitor for safety purposes and by further development of the techniques of radio guidance of aircraft by automatic means on to an airfield runway.

Acknowledgments.—Acknowledgment is made to Standard Telephones and Cables Limited, Decca Navigator Company Limited, and Marconi's Wireless Telegraph Company Limited, for the provision of some of the illustrations in the paper.

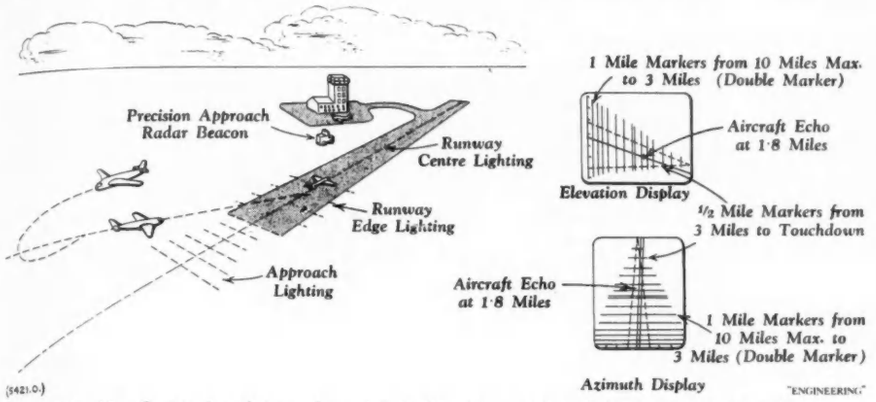

Precision Approach Radar Beacon
Runway Centre Lighting
Runway Edge Lighting
Approach Lighting
1 Mile Markers from 10 Miles Max. to 3 Miles (Double Marker)
Aircraft Echo at 1·8 Miles
Elevation Display
½ Mile Markers from 3 Miles to Touchdown
Aircraft Echo at 1·8 Miles
1 Mile Markers from 10 Miles Max. to 3 Miles (Double Marker)
Azimuth Display
(5421.O.)
"ENGINEERING"

Fig. 10 *Composite picture of an airfield Precision Approach Radar beacon (P.A.R.).*

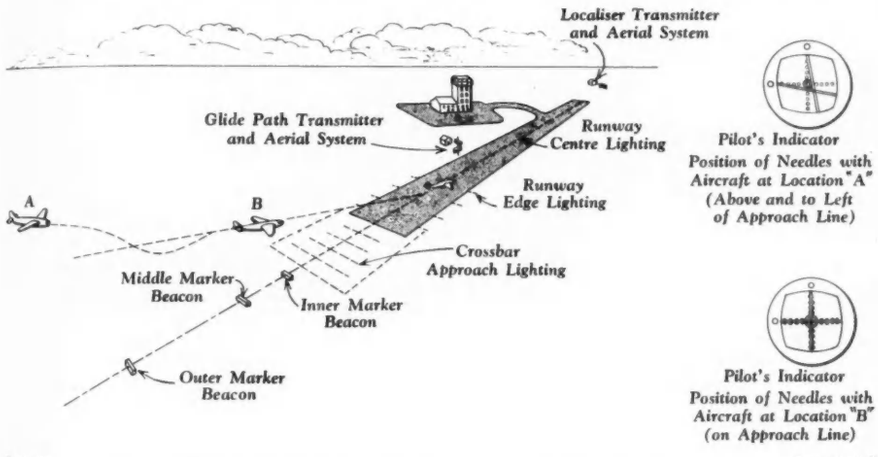


Fig. 11 *Composite picture of an aircraft Instrument Landing System (I.L.S.).*

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RADAR AIDS AT FARNBOROUGH

The imminence of the introduction of 600 m.p.h. jet air liners on some of the highest intensity traffic routes has focused attention on radio and radar aids for civil aviation.

At the Farnborough air display, Decca Radar Limited, Albert Embankment, London, S.E.11, are showing the new D.A.S.R.1 long-range civil surveillance radar recently introduced by Decca Radar for air terminals serving these new high-speed high-altitude aircraft It has coverage extending above 40,000 ft and to ranges well in excess of 100 miles. Operating in the 10 cm band this single equipment not only provides long and close coverage, from the radar horizon to well above the present limit of aircraft operating heights, but also has a high rotation rate and a narrow beam width, providing a radar picture suitable for controlling aircraft precisely and accurately even at long range. Modern techniques such as variable polarisation to eliminate weather echoes, and air target indication to suppress permanent ground echoes, are built into the radar.

The use of higher power longer-range radar equipment is complicating the problem of handling radar information within air traffic control organisations, and the importance of properly planned display systems, integrating information from more than one radar where necessary, is becoming urgent. The Decca Interscan display system is particularly suitable for operations rooms handling high traffic densities, because apart from radar information other facilities can be generated and electronically displayed to assist the controller. They include runway extension markers, geographical markers indicating the position of beacons, symbols for marking particular aircraft echoes and facilities for giving accurate positions to aircraft, relative to any point on the radar display.

Air traffic control is the main theme of the display by Marconi's Wireless Telegraph Company Limited, Chelmsford, and their Australian and Canadian associates. The Marconi control system shown is intended to augment, but not replace, existing procedural methods. A number of symbols, lines and other markers can be sequentially displayed in the radar trace fly-back time. Such markers are invaluable to operating personnel in their roles of supplementing the radar information or passing information from one display to another. Closed-circuit television as a means of passing a large amount of information to several controllers and operators forms an important part of the demonstration at Farnborough.

The airways control console uses a simple form of synthetic display. Instead of watching a first-hand PPI presentation, the display consists of symbols representing the aircraft under control (and no others). The plan positions of these symbols are identical with those of the controlled aircraft on a normal PPI and accurately keep to the same tracks. Other inter-trace markers can be displayed, together with ancillary information such as the positions of ground beacons, reporting points, etc., which are added by the use of a video map. In this way the system provides tracking without distraction, and due to the nature of the data displayed, the picture can be very considerably brighter than the normal and so may be used in a greater ambient light. It therefore becomes feasible to use the synthetic display in the same desk as the flight progress board. A television camera is incorporated to provide a picture of the controller's flight progress board. This picture is reproduced on monitor screens at the tracker's and approach controller's positions.

Another facility provided on the airways control console is the future position indicator (FPI). By means of an electronic (inter-trace) marker the controller is able to determine the time of arrival of an aircraft at a given point. Alternatively, by setting a given time on a dial the device indicates the position of the aircraft at that time, assuming that the aircraft keeps its present ground speed and track. The FPI is therefore very useful for checking a pilot's estimated time to reach his next reporting point, or for estimating whether a confliction between two or more aircraft tracks is likely to arise sometime in the near future.

There is at present considerable controversy as to whether D/F indications should be superimposed on the PPI display. In order to allow an assessment to be made under actual operational conditions, D/F super-imposition is applied to all three display consoles. In this way the facility can be seen on both synthetic and "live" radar displays. Further inter-trace markers are also provided on the PPI displays to demonstrate a simple method of handing over aircraft from an airways controller to an approach controller.

The task of the tracking operator is to ensure that the marker symbols are initially placed on the correct aircraft (this is carried out by a joystick control) and that automatic tracking is maintained thereafter. On his console, the radar display gives a picture of approximately 100 miles radius, together with a video map. Intertrace markers are also displayed, identical with those seen on the synthetic display in the airways approach console.

Once a selected symbol is superimposed on an aircraft response on the PPI display, a track-while-scan automatic tracking system takes over and maintains the symbol correctly positioned over the response, regardless of changes in speed or direction of the aircraft. A special protection circuit ensures that the system does not inadvertently "lock-on" to another aircraft which passes close to the wanted one.

Indicator lamps show whether an aircraft track is "held" or "lost" and the tracking operator has instant access to any of the symbols under his control. Should the aircraft response fade from the display the system reverts to "rate aiding"—that is, the symbol continues to move in the same direction and at the same speed as given by the last responses. Any correction necessary is automatically applied when the response reappears.

Continuing **Research and Development**

HARVESTING

A CROP of three years nuclear work, both scientific and technical, is now being harvested at the conference and exhibitions taking place in Geneva. The Second International Conference on the Peaceful Uses of Atomic Energy with its associated exhibition began on 1 September in the Palais des Nations and continues until 13 September; and the Atoms for Peace Exhibition, which runs concurrently, lasts one day more. On 22 August in an introductory article, we suggested how a number of advances in nuclear thinking may be reflected in the industrial exhibition. The article continued with descriptions of exhibits shown by companies and consortia prepared to undertake complete power reactor projects. A second article was devoted to reactor plant and instrumentation. The series continues with an account of apparatus, and experimental instruments necessary to the further development and study of nuclear energy.

Seed for a Future Harvest

Experimental Instruments

Category	Manufacturer	Instrument	Remarks	Range and size
Amplifiers	Elliott	Logarithmic amplifier. ND.141	Measurement of health ionisation chamber currents (gamma or slow neutron radiation)	10^{-7} to 10^{-12} amperes
	W. G. Pye	D.c. amplifier and micro-volt-meter	Self-contained oscillator, high feed-back factor. Zero drift $\pm 1\mu$V per day	
	Cossor	Pre-amplifier. 1440	—	Frequency range: d.c. to 50 kc/s (− 50 per cent)
Analytical Instruments	Hispano Suiza	Mechanical spectrometer (Fig. 18)	For intermediate neutrons	Resolution about 10 millimicroseconds per metre, with a flight path of 25 metres
	Mullard	Multi-channel pulse spectro-meter. L.332	100-channel " kick sorter "	—
	W. G. Pye	Argon chromatograph	Sensitivity 100,000 times greater than conventional models. Low intensity radioactive source	Will detect 10 parts in 1,000,000
	Sunvic Controls	Pulse height analyser	Ferrite-core storage matrix	
	Unicam	Spectrophotometer. SP 600	For visible range. Stray light less than 1 per cent throughout the wavelength range	Wavelength range: 3,600 Å to 10,000 Å
		Ultraviolet and visible spec-trophotometer. SP 500	New fused-silica prism permits out-standing resolution in the 190μ to 220μ region	Wavelength range: 1,860 Å to 10,000 Å
		Prism absorptiometer. SP 1400	For colorimetric or absorptiometric estimations within the 400 to 700 μ range	—
Counters	Avo	Magnetic-memory scaling unit, with magnetic indi-cator	Employs minute ferrite magnetic cores as bi-stable elements in a scale-of-ten circuit	Maximum mean count rate 250 kc/s
	Ekco	Ratemeter. N 600	Incorporates an input linear amplifier, a single-channel pulse-height analy-ser, and an adjustable H.V. supply	—
		Scintillation counter. N 618	Suitable for directional use or for body-cavity measurement. Can be cold-sterilised for in-vivo measurements. Focussing range locator	—
		Scintillation counter. N 612	Liquid phosphor. Measures very-low-energy beta emitters such as carbon 14 and tritium	—
		Scaler. N 529 Scintillation counter. N 550	Low-activity counting	—
	Electronic Instrument	Vibron pH meter	Full scale reading of 0·1 pH	—
		X-ray dosemeter	Measurement in hospitals of the amount of stray radiation received by patients in X-ray diagnosis	—
	Fleming Radio	Logarithmic ratemeter. 1508A	Five-decade ratemeter for reactor control	5 to 500,000 c.p.s.
	Kent	Universal pH recorder	Single-point, using the new Kent pH primary element immersed in hot water	—
	Isotope Developments	Scintillation counter. 700	Lead shielding and interchangeable collimators. Specially suited to human measurements	—
		Scaler. 1700	4-range ratemeter, pulse amplifier and stabilised H.V. supply and simple pulse analyser	—
		Portable scintillation coun-ter. 1413A	Sodium-iodide detector and transistor circuit, giving high sensitivity in 4 ranges	—
	Labgear	Printing counter. D.4123	Scaler/timer with integral print-out facilities, capable of 20 kc/s pulse drive	—
		Recording ratemeter. D.4124	Coupled to a strip chart recorder. Stabi-lised E.H.T. supply with amplifiers	—
		Industrial scintillation coun-ter. D.4132	Completely sealed lightweight gamma detector. Large diameter sodium-iodide crystal optically coupled to an 11-stage photomultiplier tube	—
		Clinical ratemeter. D.4130	(Derived from the ratemeter D.4124)	—
		Directional scintillation head. D.4133	Comparatively small lightweight detec-tor, with 1 in. diameter 11-stage photomultiplier tube and similarly sized sodium-iodide crystal	—
		Percentage uptake counter. D.4135	Combines timer, scaler, amplifier and E.H.T. power unit to provide auto-matic measurement for the routine diagnosis of thyroid function	—
		4-π counter. D.4126	Counting low energy alpha and beta particles in gas	—
		Well scintillation counter. D.4105/W	High-efficiency detector for low-energy gamma emitting materials. Also a medical version for routine examina-tion of urine, etc.	—
	Solartron	Field ratemeter. 1368A/A1	—	—
		Survey meter. 125A/A1	—	—
	Twentieth Century	Enriched BF3 proportional counters	Containing boron trifluoride enriched in the B.10 isotope	—
		Fast neutron counters	For use in health monitoring. Propor-tional counters employing the proton recoil method of neutron detection	0·2 MeV to 14 MeV
		X-ray proportional counters	Choice of gas fillings to suit the radia-tion employed	—
		Geiger-Muller counters	Wide range of halogen-quenched and organic-quenched counters for all applications	—
		Needle counters (Fig. 19)	Geiger counter tubes built into needles for insertion in the human body. Usually used with phosphorus (P 32)	Smallest is 2 mm. dia-meter, 10 cm long, active length located 3 mm from tip of needle, wall thickness 0·005 in.

Simulators and Computers

Computers and reactors simulators play an important part in reactor design. Reactor simulators, the controls and instruments of which correspond in behaviour and operation to those of a reactor, may also be used for training purposes. *Solartron*, for example, in addition to a wide variety of other instruments, will be showing, in conjunction with *Etelco*, photographs of a Solartron reactor simulator. Some of the units used in the simulator—a computer amplifier mounting unit, d.c. amplifier units and a heater unit—will also be on view.

Working demonstrations will be given with an *Elliott* reactor simulator type ND.181. The simulator, which was shown in Fig. 17, last week, is designed primarily for instructional purposes, and is in the form of a typical reactor control desk; all controls and indications normally available in a simple form of real reactor are provided. The unit incorporates the analogue of a reactor system constructed from standard Elliott analogue computer units, which are connected up in a manner to solve the reactor kinetics equations. Suitable outputs from the computer representing reactor power, reactor period, shut-off rod and control-rod positions, reactivity and other parameters, are indicated or recorded on instruments on the control panel. The unit may be controlled manually or use may be made of two automatic control systems, one an on-off system and the other a proportional system. As in normal practice, trips are incorporated to shut down the reactor automatically should either the power level or period pass through preset limits. Since the simulator provides an accurate indication of reactor behaviour in real time, the effect of varying conditions on reactor operation may be demonstrated.

A display featuring the Mercury high-speed electronic computer will be the principal exhibit of *Ferranti Limited*. Mercury computers are now in use at AERE, Harwell, with the French Commissariat a l'Energie Atomique in Paris, and at the Norwegian Defence Research Establishment, Oslo. A fourth machine for the European Organisation for Nuclear Research (CERN) has recently completed its performance tests and will be installed at the organisation's headquarters in Geneva before the exhibition. Altogether seven Mercury computers will be used in the nuclear field. A system has been set up for exchanging information among all users so that each benefits by the accumulated experience of all the others. The computer is designed for use in nuclear physics and design calculations. Mercury, with its high speed and huge storage capacity, was specially designed to tackle such large-scale problems. An " auto-code " has also been written for the machine which simplifies the preparation of problems and shortens the total time necessary to solve them. This makes it possible for nuclear engineers to carry out their own calculations on it. These are essentially smaller than those met with by nuclear physicists and more akin to those encountered in general engineering.

Experimental Instruments

The scope and numbers of experimental instruments have grown enormously in recent years. An indication of the range and diversity of instruments and electronic components being shown at the exhibition is given in the accompanying table. Most of the instruments men-

A THREE YEAR NUCLEAR CROP

Atomic Energy Exhibits at Geneva

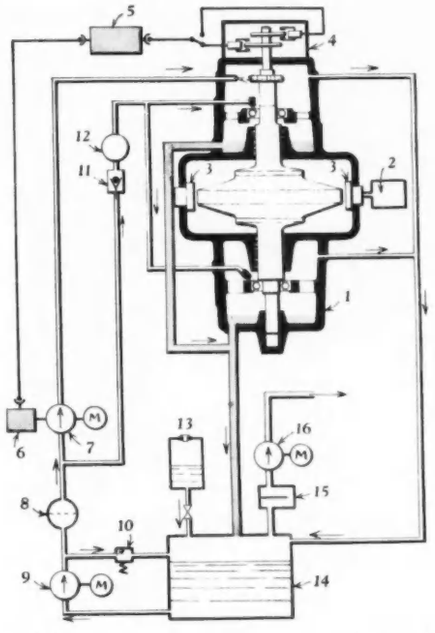
Continued from page 275, August 29

tioned are of comparatively general application; but the study of nuclear energy also requires certain special instruments. Typical of these are neutron spectrometers designed to analyse the speeds of neutrons emitted from, say, a reactor.

On the stand of *Hispano Suiza* a diagram of a mechanical spectrometer for intermediate (speed) neutrons will be displayed. Shown in Fig. 18, it uses a hydraulic transmission and has been used at the Centre d'Etudes Nucléaires de Saclay. Basically it consists of a rotating steel disc containing eight pairs of diametric channels. Two beams of neutrons, defined by input and output collimators, have their paths of travel interrupted by the disc. Thus only the neutrons

Experimental Instruments *continued*

Category	Manufacturer	Instrument	Remarks	Range
Gauges	Ekco	Nucleonic gauge. N 582 ..	Automatic programmed scanning for automatic control of production	—
		Nucleonic gauge	Utilises the *Bremsstrahlung* radiation from a strontium 90 source to measure material of thickness up to 0·4 in	—
		Gamma backscatter gauge. N 563	Measures thickness of pipe walls and other materials where access is possible from one side only	0 to 0·25 in and 0·2 to 0·75 in
		Fluid density gauge. N 611	—	..
	Isotope Developments	Portable level detector. 890	For checking the contents of gas bottles, etc. Contains a Geiger-Muller tube and a small gamma source	—
Monitors ..	Avo	Radiation monitor No. 1 (Fig. 20)	Portable and self-calibrating. Measures alpha, beta and gamma radiation on a 5 in logarithmic scale calibrated from 1 mr/hr to 5 r/hr	—
		Hot spot monitor	Portable instrument with remote ion chamber for measurement of radiation intensity in close proximity to high-level sources of beta and gamma radiation	0·1r/hr to 500r/hr
	EMI	Hand and clothing monitor	Detects alpha and beta contamination on the hands simultaneously, thus reducing the hand count to five seconds	—
	Ekco	Universal low-activity monitor. N 645	Portable monitor with transistorised ratemeter and stabilised power supplies. Alternative detector heads measure alpha, beta, gamma, slow and fast neutron radiation	—
	Fleming Radio	Radio-active air pollution recorder	—	—
		Effluent monitor	Small transistorised ratemeter with encapsulated Geiger-Muller tube	—
		Personal radiation monitor	Miniature self-contained instrument giving audible warning of contamination above a given level	—
	General Radiological	Neutron sensitive ion chambers	—	—
		Installed neutron monitors	—	—
		Alpha/beta/gamma monitors	—	—
	Isotope Developments	Package monitor. 210 ..	For checking the contents of containers on high-speed packaging lines. Measuring head incorporates a Geiger-Muller tube and a small beta source	—
	Labgear ..	Gamma monitor. D.4125	—	10mr/hr to 10,000r/hr and 1mr/hr to 1,000 r/hr
	Mullard ..	Hand and clothing monitor. L.310 series	Composite units of alpha and beta/gamma hand and clothing detector units	—
	Plessey ..	Gamma survey meter ..	Calibrated from over 3 decades to 500r/hr. For high-intensity gamma dose rates	—
	Plessey	Food Monitor	For checking contamination of liquid or solid foods	—
	W. G. Pye ..	Scalamp Fluxmeter ..	Full scale reading of 700,000 lines (0·007 weber turns) and measurements can be taken to 1,000 lines (0·00001 weber turns)	—
	Solartron ..	Personal alpa/beta/gamma monitor. 145/A1	—	—
Oscilloscopes ..	Cawkell ..	Multi-channel oscilloscope	Improved model of that used for measurements on Zeta at Harwell	—
	Cossor	Double-beam oscillograph. 1035 Mk. III	Provision has been made to trigger the time-base from either line or frame pulses in a composite video signal	Output deflection, with the A1 amplifier, on all ranges of not less than 2 cm peak-to-peak over the range 5 c/s to 7 Mc/s
		Double-beam wide-band oscillograph. 1059	Sensitivity of the calibrated amplifiers is continuously variable between 0·1 V/cm to 10 V/cm over a working bandwidth of 5 c/s to 10 Mc/s. An X amplifier allows a continuously variable sweep expansion up to five times	—
		Double-beam oscillograph. 1049 Mk. IV	Direct-coupled amplifiers provide gains of 900 (Y1) and 30 (Y2) and with frequency response from zero to 400 kc/s (Y1) and 800 kc/s respectively	—
		Oscillograph monitor. 1043	Designed for use in conjunction with Model 1049	—
	EMI	General-purpose wide-band oscilloscope WM7 (Fig. 21)	—	—
	Fleming Radio..	Oscilloscope. 1329B ..	Primarily for use on fast pulse circuits incorporating special features	—
	Mullard ..	Precision wide-band oscilloscope. L155	Rise-time of 0·014 microsecond. The *y* channel incorporates a three-stage directly coupled amplifier and has a bandwidth of d.c. to 25 mc/s. Maximum sensitivity is 150 mV peak-to-peak/cm. Sweep times down to 1·5 microseconds are available and the sweep length may be expanded up to five screen diameters	—
	Solartron ..	Solarscope. CD711S	—	—
		Solarscope. CD814	—	—



(5670 A) "ENGINEERING"

Fig. 18 Mechanical spectrometer for intermediate neutrons comprising a rotary steel disc pierced by eight pairs of diametric channels (Hispano Suiza).

1. Body of the spectrometer.
2. Remote-controlled semi-automatic charging device.
3. Entry and exit collimators.
4. Frequency meter speed detector.
5. Regulator/controller/governor.
6. Electro-hydraulic servo-mechanism for speed control.
7. Electric motor-pump (high pressure).
8. Filter (low pressure).
9. Immersed low-pressure pump with electric drive.
10. Delivery/discharge valve.
11. Anti-return valve/clack.
12. Accumulator.
13. Compensating oil reservoir.
14. Oil reservoir.
15. Oil-air separator.
16. Vacuum/void pump.
17. Entry-collimator remote-retraction device.

Fig. 19 Needle Geiger counters made by 20th Century Electronics for inserting into the human body.

Fig. 20 Avo portable radiation monitor No. 1.

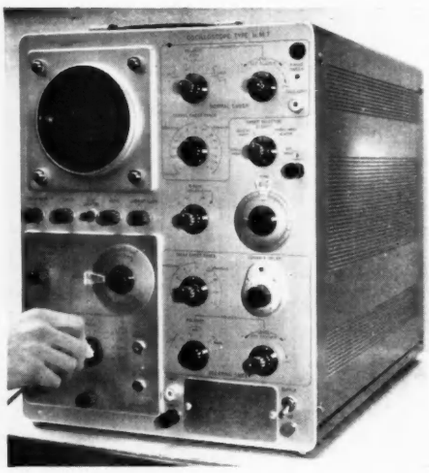


Fig. 21 EMI wide-band general-purpose oscilloscope.

above a certain well defined speed will be able to travel down the channels in the disc without being absorbed by the steel. The rotor is of forged steel and has a diameter of 48 cm and a weight of 95 kg. The maximum speed for continuous operation is 15,000 r.p.m., which corresponds to a peripheral velocity of 375 metres per sec. The channels are spaced so that the members of a pair are 24 mm apart, and the width of each channel at the entry is 0·1 mm ± 0·01 mm. With a flight path of 25 metres, the resolution obtainable is about 10 millimicroseconds per metre.

General analytical instruments include the nuclear magnetic resonance spectrometer made by the *Fairey Aviation Company Limited*. It is of medium-high resolution and designed for chemical analysis and research.

Experimental Instruments *continued*

Category	Manufacturer	Instrument	Remarks	Range
Pulse generators	Cossor	Milli-microsecond pulse generator. 1046	Can be used in conjunction with a suitable oscillograph to examine the step response of wide-band amplifiers with frequency responses extending to several hundred megacycles per second	—
	Dawe Instruments	Pulse generator. 412B ..	General-purpose instrument with a wide recurrence frequency range from 25 c/s to 100 kc/s with a pulse width continuously variable from 0·3 microseconds to 60 milliseconds	—
	Fleming Radio..	Crystal controlled pulse generator. 1478A	Designed for setting up scalers, rate-meters, etc.	—
		Fast-multiple pulse generator. 1147B	A generator with two output pulses having short rise times suitable for testing coincidence units and other units with fast rising pulse inputs	—
	Mullard ..	Precision pulse generator. L141	Amplitude of the two main pulses is continuously variable between 300 microvolts and 100 V, their duration from 0·5 to 100 microseconds, and the separation between them from 0 to 100 milliseconds. An internal oscillator provides repetition frequencies from 1 c/s to 100 kc/s	—
	Solartron ..	Pulse generator. 104A/A1	General test equipment	—
		Delay generator. 104A/A2	General test equipment	—
Test instruments and balances	Avo	Avo transistor tester ..	Enables a component to be tested without the necessity of its removal from the circuit	—
		Photo transistor relay meter	Modified form of moving coil meter	—
	Cambridge ..	Universal vibrograph ..	Horizontal and vertical vibrations, and, with a special attachment, variations in rotational velocity	—
	Cossor	Transistor tester. 1325	Direct measurement of the large signal current amplification factor beta collector turnover voltage V_T and the collector-emitter $I'c(o)$ of p-n-p and n-p-n transistors	—
		Millimicrosecond pulse test set. 1060	Designed to test passive and active networks by pulse technique and comprises an adjustable pulse source, a display oscillograph and power units. A free-running blocking oscillator and shaping circuits generate pulses variable up to approximately 250 V peak amplitude and of substantially $\sin^2$ shape adjustable in width to 5, 20 or 50 μsec. The oscillator also provides the sawtooth voltage for the oscillograph time base	—
	Dawe Instruments	Sound level meter. 1400	May be used in conjunction with Audio Frequency Analyser (1400)	—
	Electronic Instruments	Vibron gamma-ray electrometer	Measurement of the concentration of uranium ore in a slurry flowing through a steel pipe	—
		Vibron laboratory electrometers	—	Currents of 10^{-16} and resistances in excess of 10^{15} ohms
	Elliott	Micro-microammeter. ND12	For the measurement of ionisation chamber currents in six switched linear ranges between 10^{-6} and 10^{-11} amperes	—
	W. G. Pye ..	Universal measuring microscope and cathetometer.	—	Range 50 cm Vernier reading to 0·05 cm. Fine adjustment slide of range 30 mm, with micrometer head reading to 0·005 mm
		Portable Wheatstone bridge	Self-contained	—
		40 kV electrostatic voltmeter	Direct reading up to 40 kV d.c. or 40 kV rms a.c. regardless of waveform. Battery or mains	—
		Scalamp electrostatic voltmeter	Portable	Full scale voltages from 5 to 20 kV
		High resistance Test set ..	Battery operated	Resistances up to two million megohms
	Stanton Instruments	Ultramatic single-pan balance	Weights applied by bench level controls; also partial release system	Up to 200 gm
		Thermobalance. (Fig. 22)	Model A42 or A44 balance surmounted by controlled furnace and twin-pen electronic recorder	1,000° C and 1,400° C models; 1 or 0·1 milligram sensitivity

Particle Accelerators

Particle accelerators are research instruments of first importance since with their aid the structure of the atomic nucleus may be ascertained. The 30 ft high accelerating column of a 6 million volt Van de Graaff machine will dominate the exhibit of *High Voltage Engineering Corporation*. The column, together with its beam analysing magnet, are the principal components of a giant positive-ion accelerator used primarily for neutron cross-section studies, nuclear-energy level determinations and related basic physics research programmes. The unit is destined for the University of Strasbourg in France, following the exhibition. The High Voltage display features the various types of accelerators manufactured by the company, and the applications of each in scientific research, industry and medicine. Also on display will be a scale model of the company's new tandem Van de Graaff machine, a 10 million volt accelerator designed especially for physics research in an energy range not previously studied. This machine consists of two 5 million volt Van de Graaff accelerators placed end to end, measures some 35 ft in length and weighs about 35 tons.

Metropolitan-Vickers will show photographs on the AEI—John Thompson stand of the 25 MeV electron linear accelerator under construction for the United Kingdom Atomic Energy Authority. Photographs will also be shown on the *Union Carbide Corporation* stand representing the 86 in synchro-cyclotron at the Oak Ridge National Laboratory, USA, which the company operates for the USAEC.

Fusion Apparatus

ZETA (zero-energy thermonuclear assembly) figures prominently among the photographic exhibits of *Metropolitan-Vickers*, who, after collaborating in the first design and functioning as main contractor for its construction, are also associated with the modifications now in progress. *Cawkell Research and Electronics Limited* are showing an improved model of the multi-channel oscilloscope used in measurements on ZETA.

The *Union Carbide Corporation* record in their exhibit the progress of Project Sherwood, the United States Atomic Energy Commission's programme of controlled thermonuclear fusion research. The focal point is a large schematic model of DCX, the Oak Ridge National Laboratory experimental fusion device which Union Carbide scientists have developed, and now operate. The exhibit begins with a short definition of fusion and traces the steps necessary to arrive at the controlled fusion reactor.

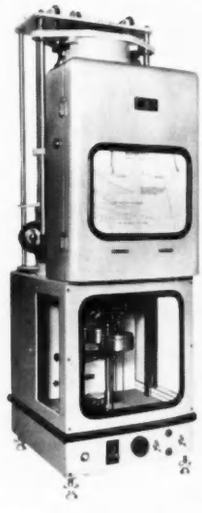


Fig. 22 Stanton thermobalance.

A final article will consider nuclear energy materials. A list of firms mentioned in that and the present article, their addresses and stand numbers appears on page 301 of this issue.

Book Reviews

SIGHT AND SOUND TAPED

Magnetic Tape Recording. By H. G. M. SPRATT. *Heywood and Company Limited, Ingersoll House, 9 Kingsway, London, W.C.2.* (55*s.*)

The process of magnetic recording consists of magnetising a moving magnetic tape along its length in a pattern which corresponds to the time variations in electrical signals being fed to the recording head. Each frequency in the signal being recorded has thus a corresponding wavelength on the tape. In reproduction the tape is passed over a reproducing head which transforms the magnetic variations back into time variations of e.m.f. The limitations of the system have been, and still are, defined by the various losses, dependent on both wavelength and frequency, which occur in recording and reproducing.

Although a patent for a form of magnetic recording was granted to Valdamar Poulsen at the end of the last century, the system may be said to have become of first importance to industry and entertainment only since the end of the 1939-45 war. This is largely due to the development by the Germans, during the war, of the oxide-coated, plastics-based tape which has great advantages over the earlier steel tape or wire in terms of frequency response, noise level and ease of handling. The post-war progress of magnetic recording may be judged by the reflection that in 1945 the use of the system for high-quality sound recording was being seriously considered, and now its introduction into television broadcasting as a means of recording both sound and vision is being actively pursued. This represents an extension of the bandwidth recorded by a factor of some two hundred, an advance which would have been inconceivable with metal tape. It also implies, however, great developments in head design and in the means by which the original timing accuracy of the signals recorded on the medium is maintained in reproduction. These have been made possible by modern developments in magnetic materials and servo-mechanism techniques.

Mr. Spratt's book does not attempt fully to cover the recording aspects of these or other very advanced fields but it does provide coverage of all the important general aspects of magnetic recording and illustrates the properties of both the system and of the materials employed in it which have provided the impetus and foundations for development. It thus forms excellent basic reading for the consideration of current or envisaged uses of the technique, and fills a notable gap in the technical library. The bibliography provided at the end of each chapter gives a lead when more extensive and detailed investigation is required.

The early chapters of the book are concerned with a survey of the basic principles of general magnetism and of those aspects of sound reproduction and electro-acoustics which are relevant to the context. The basic principles of magnetic recording are then set out and the nature of the frequency and wavelength phenomena which lead to the recording, reproducing and noise characteristics obtained in practice are investigated. Three chapters on tape materials, tape manufacture and tape testing follow, these being aspects of the subject with which Mr. Spratt has a very close acquaintance. Further chapters deal with the electronic and mechanical aspects of tape recording machines and with general design trends. Two chapters on applications and developments give the reader some idea of the wide capabilities of the system and of what it might reasonably be expected to accomplish in the near future. Finally there is a chapter on recording standardisation, a subject which has not hitherto been covered in any text book. This is particularly valuable at the present time when international standardisation of recording characteristics and of various mechanical aspects of machines and tapes employed for common purposes in sound recording and computers is being energetically pursued. The book will be valuable to those with a basic electrical engineering knowledge who wish to become acquainted with the subject and also to those employed in any part of the field who desire a broad survey of the whole of it.

NEW BOOKS

Analysis and Control of Nonlinear Systems. By Y. H. KU. *The Ronald Press Company, 15 East 26th Street, New York 10, N.Y., U.S.A.* (10 *dol.*)

The book is intended to provide electrical and mechanical engineers, physicists and applied mathematicians with an account of the available techniques for the analysis and control of nonlinear physical systems. It is based on a graduate course in nonlinear circuit analysis. Both analytical and topological methods of solving nonlinear differential equations are presented, covering both mechanical vibrations and electrical oscillations. The reader is expected to utilise the analogy between mechanical and electrical systems so that a given solution for a problem in a mechanical system can be utilised to solve a similar problem in the electrical system and vice versa; hydro systems and acoustic systems can be studied in like manner. A new approach has been developed for the treatment of third and higher order nonlinear differential equations based on the author's method of space trajectory in N dimensions, which extends the phase plane method in phase space. The ground covered includes linear and nonlinear systems; mechanical vibrations and electrical oscillations; nonlinear system with damping; classification of singularities; autonomous system with nonlinear damping; nonlinear system with force function; subharmonics; analysis of high order nonlinear systems; analysis of multi-loop nonlinear systems; the analysis of nonlinear servomechanisms and nonlinear control of feedback systems. The bibliography includes 735 references and problems are set at the end of each chapter.

TRADE PUBLICATIONS

Copies of any of the following trade publications are obtainable from the addresses given, though distribution is sometimes restricted.

Drill Heads. STUART DAVIS LIMITED, Much Park Street, Coventry. "Hydroair" drill head units, left or right hand control, driven by a $\frac{1}{3}$ h.p. motor mounted either in line or above the head. Choice of seven speeds. Spindle travel $1\frac{3}{4}$ in; chuck capacity $\frac{5}{16}$ in drill in mild steel; maximum feed travel $1\frac{1}{2}$ in. Leaflet.

Sheet Metal Working. F. J. EDWARDS LIMITED, 359/361 Euston Road, London, N.W.1. The "Besco" range of sheet metal working machines, including benders, formers, guillotines, press brakes, shears and saws. Thirty-page catalogue.

Daylight Partitioning. JOHN WILLIAMS & SONS (CARDIFF) LTD., East Moors Road, Cardiff. Lita unit-system steel partitions for "Walls of Daylight." Illustrated brochure.

Mould-Release Agent. ADDISON ELECTRIC CO. LTD., Adelco Works, Bosworth Road, London, W.10. "Bomb-Lube," silicone-based aerosol mould-release agent; its properties, advantages and scope. Leaflet.

Diaphragm Pump. KESTNER EVAPORATOR AND ENGINEERING CO. LTD., 5 Grosvenor Gardens, London, S.W.1. Glandless self-priming diaphragm pump suitable for acids and acid slurries. Illustrated leaflet.

On the Shelf

By Frank H. Smith

I just love digests of digests, abstracts of abstracts, bibliographies of bibliographies, and so on. They all remind me of the business of the trademark of somebody who is looking at himself, and who, in turn, is looking at himself—like that light experiment of sitting between two parallel facing mirrors. And here is G. P. Henderson's *Current British Directories*, third edition, by Jones and Evans Bookshop Limited, 70 Queen Victoria Street, London, E.C.4, at 30*s.* plus 2*s.* postage. As a matter of fact, the leaflet I have, does convince me that this is a most useful reference tool.

A booklet issued by the City and Guilds of London Institute, Gresham College, Basinghall Street, E.C.2, summarises the main changes in the regulations and syllabuses of existing subjects, and of new schemes being introduced in the session 1958-59. For instance, a section dealing with wines has been added to Advanced Domestic Cookery. The Technical Authorship syllabus, about which there was a certain amount of song and dance, is also mentioned.

Do you know the difference between PANSDOC and INSDOC? Neither did I until I read a Press Release from UNESCO (you know that one) on the completion of the first year of Pakistan's Scientific Documentation Centre—that's PANSDOC. The moving spirit was Mr. A. L. Gardner—"a veteran of technical assistance"—who also set up INSDOC, which, one assumes, is India's Scientific Documentation Centre. Originally, Mr. Gardner was gunnery officer in the Royal Navy—SHIPSDOCK.

The Institute of Welding now has an "annual lecture," the first of which is published in the July number of the *British Welding Journal*. It is by Sir Alfred Pugsley on "The Influence of Welding on Structural Design," and in his preamble Sir Alfred is careful to point out that he is an engineer and not a welder.

Aslib Publications is the name of a four-page (if you do not include the covers) leaflet from 3 Belgrave Square, London, S.W.1. There is no need for me to describe the contents since it will, apparently, only cost you a postcard to have a copy all to yourself. I would mention, however, that the list includes the offprints from *Aslib Proceedings* and the *Journal of Documentation* and a glance down these titles gives one an amusing exercise in conjecture as to what governs an offprint being made.

Just in case you are interested, the International Press Service of America (P.O. Box 77, Brooklyn 23, N.Y.) offers more than 1,500 photographs of United States air power. It costs a mere 800 dol, unless you happen to belong to the IPA News Syndicate for Aeronautics when it will cost you only (sic) 600 dol.

I think Mr. Ray Gregory, the PRO of the Carborundum Company Limited, Trafford Park, Manchester, has been reading this column. Otherwise why should he send me two of that company's "Brief Case Series" entitled "Letter Writing" and "Report Writing" which contain the usual exhortations about good writing in these two fields. However, they are extremely readable little booklets (designed for brief cases about $5\frac{1}{2}$ in by $4\frac{1}{4}$ in). For instance, ". . . a report on the cost of a cup of tea in the Works Canteen does not call for an appraisal of the North Atlantic Alliance." On the other hand, if I were to follow "Say what you mean. Be yourself" all the time, I might land in trouble. And what about "Avoid the temptation to show off"? Ugh!

On page 91 (ENGRG., 18 July) I remarked on the change of title of the *Aeronautical Engineering Review* (U.S.) to the ghastly *Aero/Space Engineering*. With the July number of their journal, which used to be called *Journal of the Aeronautical Sciences*, they have gone still further haywire and changed that—in the middle of a volume to boot—to *Journal of the Aero/Space Sciences*.

Engineering at Home

SOUND DEVELOPMENT

Radio sets are still represented at the 1958 Radio Show, held at Earls Court from 27 August to 6 September, although manufacturers are not able to offer any significant technical advances over last year's models. Printed circuits are widely used and experience in the technique has led to a better appreciation of layout problems. More car radios are shown, and several transistorised versions make their appearance. Cossor Radio and Television Limited, Highbury Grove, London, N.5, are displaying the model 569 Transistor Six—an all-transistor radio that will plug into a car aerial. E. K. Cole Limited, Southend-on-Sea, Essex, are exhibiting their model CR901, which operates direct from the 12 volt car battery and requires no power unit, thus avoiding the background noise that such units often make. The set employs two transistors in a push-pull output stage, a diode, and four thermionic valves. A tuned radio-frequency stage is incorporated. Both manual and push-button selection are provided, and installation kits are available to suit various cars.

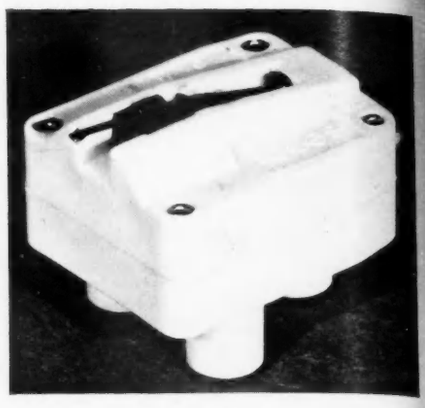
A great variety of small battery and mains portable receivers are on display, the cheapest being 10 gns. Transistor portables are, however, still dearer than their valved counterparts. In the first half of this year portable radios made up 41 per cent of the total number of radio sets sold, compared with 30 per cent for 1955.

The figures for the sale of television receivers reflect the growing demand for larger sets, although the 17 in screen is still the most favoured, having increased its popularity over both the 14 in and 21 in versions. The main change noticeable at the Radio Show is the reduction in cabinet size. Various design changes have contributed to this, one being the general use of a cathode-ray tube in which the electron beam sweeps through 90°. Siemens Edison Swan Limited, 155 Charing Cross Road, London, W.C.2, are showing an electrostatically focussed tube of this type: it is a 17 in rectangular tube and has a total length of 15 in.

Another way in which cabinet size is being reduced is by pushing the tube face through the surrounding mask, instead of having the mask overlapping the tube edge. Also, new chassis arrangements have led to space saving, for example, by the wider use of printed boards instead of the more conventional chassis. A different line of development is displayed by Radio and Allied Industries Limited, Slough, Buckinghamshire, (Sobell and McMichael). Two circuit panels are mounted on hinged chassis members so that they can be pulled down clear of the cabinet for easy adjustment. Plated circuits are used instead of etched circuits, the makers claiming that greater flexibility in the placing of components is allowed by this technique.

A novel chassis layout is also a feature of the set shown by A. J. Balcome Limited, 52-70 Tabernacle Street, London, E.C.2. As will be seen from the illustration, it is made up of four main panels. They plug together and the company run an exchange scheme of sealed factory tested panels to replace any panel in which a fault develops. The operation can be carried out without moving the main chassis and without soldering. The company consider that 90 per cent of all possible faults can be cured in this way, so that very rapid servicing is offered to users. The set, the Alba T655, incorporates a 17 in tube.

Features of this year's show are the large amount of space given to audio equipment and the introduction of stereophonic reproducers by several manufacturers. Also, many conventional radiograms are displayed as "wired for stereo"—that is, a plug-in stereo head and an add-on amplifier-loudspeaker unit can be purchased later when needed. Hobday Brothers Limited, 21-27 Great Eastern Street, London, E.C.2, are exhibiting a stereophonic radiogram in which the speakers for each channel are situated on pull-out panels at either side of a broad console. When pulled out, the speakers have a separation of 5 ft 5 in. Both stereophonic and monaural records can be played. In the latter case, and on the radio setting, the twin audio channels are connected in parallel.

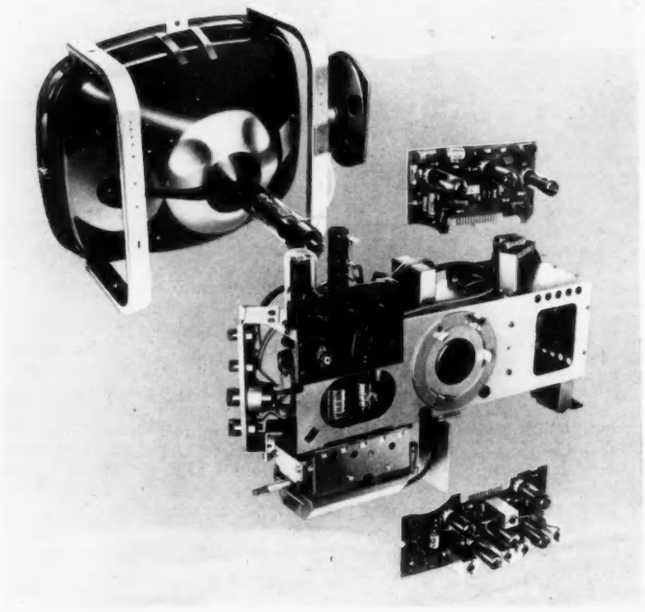


The "Acostereo" cartridge conforms to the recent international conventions agreed upon for stereophonic recordings.

A low-cost stereophonic record player is displayed by the Radio Gramophone Development Company, Romford, Essex. It is in two parts, the main cabinet (housing a 5 in speaker) being only 18 in by 9 in by 15 in. A smaller cabinet contains an 8 in by 5 in loudspeaker.

A pick-up cartridge designed for stereophonic reproduction must have a stylus with equal vertical and horizontal compliances; it will be suitable for playing normal monaural microgroove records. However, although the majority of conventional monaural pick-up styli have an adequate horizontal compliance, very few have an equal vertical compliance, and so are not suitable for playing stereophonic discs. Conventions for stereophonic recordings have been agreed upon by an *ad hoc* committee of British and European record manufacturers, and confirmed by the Record Industry Association of America. Speed, diameter, and recording characteristics are the same as for existing standards of microgroove records, but stylus radii are recommended to be 12·5 micron minimum and 15 micron maximum.

The "Acostereo" crystal cartridge, made by Cosmocord Limited, Waltham Cross, Hertfordshire, conforms to the standard. It will track at a minimum of 2 grammes and the separation between channels at 1 kc/s is better than 15 dB. The frequency response extends from 40 to 12,000 c/s and the output is 200 mV at 1·5 cm per sec. A stereophonic pick-up is also shown by Decca Radio and Television, 1-3 Brixton Road, London, S.W.9. Equipped with a diamond stylus, a tip mass of less than 1 milligram is realised; the playing weight is 3·5 grams. Cross-talk is about — 20 dB and the frequency response is within 1 dB of the R.I.A.A. recording characteristic.



The Alba television receiver is made up of four main units. Its makers run an exchange scheme whereby a sealed tested panel replaces any panel in which a fault develops. They consider that 90 per cent of all possible faults can be dealt with in this way.

ENGINEERING

Published every Friday by ENGINEERING LTD. at 36 Bedford-street, London, W.C.2.
Telephone: Temple Bar 3663.
Telegrams: Engineering Lesquare London.

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